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DEVELOPMENT OF AN EVALUATION MODEL FOR REVERSE SUPPLY CHAIN BUSINESS MODELS

PEDRO JOEL COSTA GOMES
DISSERTAÇÃO DE MESTRADO APRESENTADA
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Development of an evaluation model for reverse supply chain business models

Pedro Joel Costa Gomes

Dissertação de Mestrado

Orientador na FEUP: Prof. Eduardo José Rego Gil da Costa

Orientador no Instituto: Prof. Dr. Günther Schuh

Faculdade de Engenharia da Universidade do Porto

Mestrado Integrado em Engenharia Mecânica

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To my parents for their never ending support during this project

Desenvolvimento de um Modelo de Avaliação de Modelos de Negócios de *Reverse Supply Chains*

Resumo

A necessidade de estudar a viabilidade de exploração de modelos de negócios relativos a uma r*everse supply chain* surge impulsionada por novas tendências de consumo, por diretivas que limitam a sobre-exploração ou forçam a recolha de materiais nocivos ou tóxicos, visando mitigar o peso ecológico de produtos usados destruídos ou descartados, e por estratégias de negócio sustentáveis

Um exemplo da necessidade de recorrer à recuperação de produtos usados surge da expectativa do crescimento da procura de veículos elétricos e da consequente escassez dos recursos necessários à produção das suas baterias, que induzem novos compromissos e desafios a produtores e respetivos gestores de cadeia de abastecimento.

Assim, entendendo-se como fundamental a existência de recursos e métodos que permitam a recolha e recuperação de produtos usados melhorando a sua eficiência ao longo do seu ciclo de vida, procura-se a implementação de modelos de negócio que permitam o aumento das taxas de reutilização, de remanufatura e de reciclagem, aumentando por um lado a acessibilidade dos produtores às matérias-primas e, ao mesmo tempo, garantindo a operacionalidade da empresa.

Para isso será necessário o desenvolvimento de uma ferramenta de avaliação das interdependências entre vários parâmetros da cadeia de abastecimento, nomeadamente, o valor residual do produto e o seu índice de desmontagem e dos diferentes modelos de negócios passiveis de aplicação.

No presente trabalho foi estudada a influência dos parâmetros relativos à cadeia de abastecimento na performance dos diversos modelos de negócios e foi desenvolvido um modelo que visa simular as componentes de custos e receitas baseando-se na metodologia de análise de sistemas dinâmicos, *system dynamics.*

O estudo da influência dos parâmetros influenciadores foi feito através da recolha e da análise bibliográfica de outros sistemas qualitativos e quantitativos de avaliação.

Foi desenvolvido um modelo usando o software VENSIM, cuja validação passou pela definição do ponto de equilíbrio da cadeia de abastecimento e pela relação dos fatores inerentes a esse equilíbrio com a aplicação de diferentes modelos de negócio.

O resultado final contempla um modelo que relaciona o lucro e ROCE (*Return of Capital Employed)* relativo aos diferentes modelos de negócio estudados.

Development of an Evaluation Model for Reverse Supply Chain Business Models

Abstract

The necessity to study the exploration viability of business models pertaining r*everse supply chains* emerges driven by new consumer tendencies, by directives limiting the overexploitation or forcing the recovery of manufactured products, seeking to alleviate the weight of destroyed or discarded used products

An example of the necessity to resort to product recovery activities arises from the expectation of the rise of electrical vehicles demand and the scarcity of the resources needed for their batteries production that introduces new compromises and challenges to manufacturers and supply chain managers. Therefore it is understood as being of the utmost importance the existence of resources and methods that allow for a recovery and retrieval of used products improving their life cycle efficiency, aiming for the implementation of business models that promote and increase the reusing, remanufacturing and recycling rates, easing the process of accessing the raw materials required while simultaneously safeguarding the operability of the company.

Therefore it is necessary to develop a tool for the different business model types liable to be used to evaluate the interdependences between various parameters of the supply chain, namely the product's residual product and disassembly index.

In the present dissertation the influence of such parameters in the performance of the different business models has been studied and a model based on the system dynamics approach has been developed in order to simulate the cost and revenue components.

The study of the parameters influence was made based on existing bibliography analyses of other qualitative and quantitative evaluation models.

A model using the software VENSIM has been developed and validated with the definition of the break-even point of the supply chain and the relation of the different factors applied to different business models.

The final results consist of a working model relating the profit and ROCE (Return of Capital Employed) of the different business models.

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List of Abbreviations

BM	Business model
CLSC	Closed loop supply chain
DES	Discrete event simulation
EOL	End of Life
FSC	Forward supply chain
i.e	In example
OEM.	Original equipment manufacturer
p.	Page
ROCE	Return on Capital Employed
RSC	Reverse supply chain

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1 Introduction

The present dissertation was developed during an ERASMUS semester at the Rheinisch-Westfälische Technische Hochschule (RWTH-Aachen) in the scope of the Master in Industrial Engineering and Management, at the Faculty of Engineering of the University of Porto.

The project was held under the supervision of the production management department of FIR at the RWTH-Aachen University, which consists of a non-profit and inter-sectorial research organization focused on business organisation and corporate development that provides research, qualification programmes and lectures in the service management, information management, production management and business transformation fields.

Founded in 1953 the institute belongs to the technological cluster of the university forming a part of the initiative for excellence in North Rhine.Westphalia (NRW), aiming to promote the strengths, expand and consolidate excellences in NRW.

Considering innovative supply chain management concepts, the research group supply chain management belonging to the abovementioned production management department works on the strategic design of value added networks and chains, including long-term planning, modelling and optimisation of cross-company material, goods and information flows helping companies planning the network structure and location selection. Furthermore, the group is responsible for the design, establishment and maintenance of the relations with the suppliers and customer as well as between a company's own facilities, capacities, production and storage facilities.

1.1 Initial Situation and Challenges

While in the last twenty years, the focus has been directed on the adjustment of the product flow from raw material to the end customer, a paradigm shift in the way the returned goods are seen from the public, firms and governing bodies saw an increase in the attention given to reverse supply chains.

Saturated disposal areas, the ever faster depletion of raw materials and global warming have evoked the need for new environmental regulations and directives to return the end of life products through a reverse supply chain (RSC). An example is the pressure laid upon European tyre manufacturers after the European Council Directive 1999/31/EC on the landfill of waste. According to this legal act Member States are to take measures in order that used whole and shredded tyres starting from respectively two and five years after the established date (although varying by country) are not accepted in a landfill (European Council 4/26/1999). This is put into practice, among other means, through a producer responsibility strategy in which the law establishes the legal framework and assigns the responsibility to the producers to organize and manage the reversed chain of end-of-life (EOL) tyres (ETMra 2011).

Another example was directed towards electrical and electronic equipment, where the Directive 2002/96/EC of the European Parliament and of the Council on waste and electronic equipment (WEEE) imposes the responsibility for the disposal of this waste on the manufacturers or distributors of such equipment. In response to this, some manufacturers have arranged a cooperative collection and recycling network of regional storage centres where products collected by municipalities and retailers are sorted and shipped to recycling subcontractors (Fleischmann 2001) .

Additionally some manufacturers and distributors are forced to plan a solution for their EOL products. However many manufacturers and distributors take this option pro-actively attracted by the residual value of used products.

This opposes the traditional approach many manufacturers had when not bound to any legal obligation which was regarding commercial product returns to be an inconvenience. As the final consumer was not prepared to pay for a green fee helping support the backward movement of the used good, it was believed that the costs of incorporating the disposal requirements would outweigh its benefits meaning that decisions were based on the purchasing costs reduction instead the optimization of the life-cycle performance. (Thierry et al.).

As such, the first question one has to ask when considering engaging on recovery efforts is whether or not such activities would turn profitable or if it would be a better option for the original equipment manufacturer, OEM, to regard the disposal costs of obsolete products as sunk costs.

This depends strongly on several external factors, namely existing legislation, raw material acquisition costs and attractiveness of the secondary market. However, today in an effort to increase customer retention rates many OEM have implemented increasingly liberal return policies which, added to the rapidly increasing volume of products derived from internet based business, led to an escalation of the amount of customer returns which will require a well-designed reverse logistic network to handle these products minimizing the derived costs.

This change of marketing and sales methods as well as the changes of customer mentalities can lead some companies' decisions to a standstill facing the trade-off between the efficiency of the supply chain and the time wasted from the point when a product is returned to its reintegration in the forward supply chain and subsequent loss of value and likelihood of its viable reuse.

In an ideal case, the OEM would make profit from the recovering activities and establish an image of an environmental friendly company while the customer benefits from a price reduction of the remanufactured products and the environment is conserved from overexploitation of resources.

1.2 Target of the work

Considering the previously mentioned challenges, the target of this work is to provide a tool based on a system dynamics simulation model capable of assessing the performance evaluation of an implemented or designed reverse supply chain in order to aid the management of a company interested or expecting to engage in recovery activities in the decision making process. Using the simulation model provided, the original equipment manufacturer should be capable of both choosing the best contract option for its products and its optimal duration, that is, upon an hypothetical recovery of a previous leased product, the OEM should be able to decide whether or not an extension of the leased period is more profitable than the recovery and remanufacture of the product aiming to a re-sale.

To that end, focusing on the economic dimension of the driving forces' triangle suggested by (de Brito, Marisa P., Dekker 2003), the value flows originated from the different reverse supply chain business models studied will be analysed in search for breakeven points that reveal the conditions where a particular business model is preferable in comparison with the other options.

1.3 Structure and Procedure

To achieve the result proposed in the previous section, the structure depicted in figure 1.1 was idealized. The work will be divided into two parts, the first consisting in the research of the fundamental concepts and the available developments made in similar studies and the second consisting in the design, implementation and validity of an evaluation model for reverse supply chain business models using the software VENSIM.

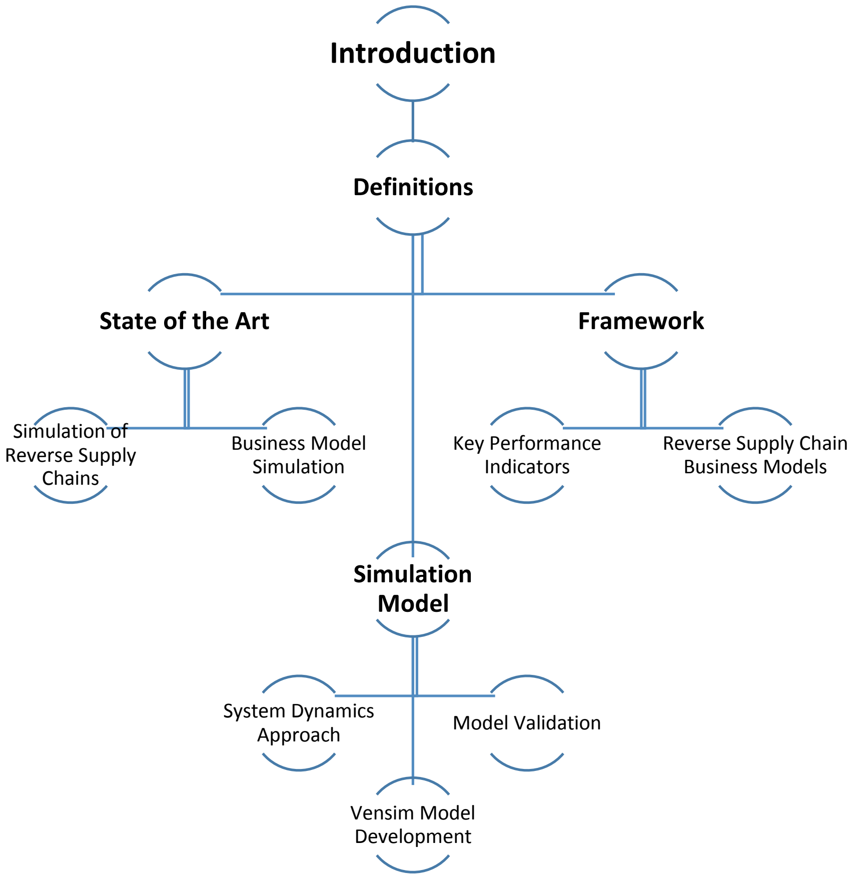


Figure 1.1 - Procedure followed in the course of this work

2 Definitions

The purpose of the following chapter will be the historic introduction and explanation of the reverse supply chain and business model concepts along with the reasons for their existence using the available literature as reference, while simultaneously providing a basic knowledge of the fundamental notions supporting these two core concepts through a comparison between the analyses of some existing approaches.

2.1 Reverse Supply Chain

The reverse supply chain is usually defined as the sequence of activities required to retrieve a returned product from its user and either dispose or reuse it with the goal of recovering as much economic and ecological value retained in the products as possible. The scope of the concept of the reverse supply chain is still disputed by some authors. Indeed the relatively new and empirical research in the area caused the emergence of numerous terms, namely reversed logistics, return logistics or retro logistics, broadly referring to the same concept (de Brito, Marisa P., Dekker 2003).

Therefore, in an effort to avoid misunderstandings due to the diversity of definitions and in some degree, a noticeable interchangeability of both the concepts of reverse logistics' network and reverse supply chain in some literature, it is important to clearly define them clarifying the proposed differences between both definitions and their exact meanings according to different authors.

(Dyckhoff et al. 2004) refer to reverse logistics as "*all activities involved in managing, processing, reducing and disposing of hazardous or non-hazardous waste from production, packaging and use of products, including the processes of reverse distribution"* (Dyckhoff et al. 2004, p. 164), comprised of five main processes: collection, sorting, transportation, warehousing and processing.

Although the understanding of these five processes as the fundamental processes of a reverse supply chain remains throughout the literature reasonably unchanged, there are some deviations apart from the terminology used, which should be noted.

The term reverse logistics is also applied to define the sequence of activities required for the transportation of products returned by customers to sorting and disposal facilities (Blackburn et al. 2004). In that case, according to Blackburn et al. the reversed supply chain assumes the form illustrated in figure 2.1. This analysis shifts the previous concern on storage activities, which are incorporated on the reverse logistics and inspection and disposal processes. A relevant adjustment is also noticeable in the last stage of the chain. Whereas other authors' studies ended on the processing phases, Blackburn et al. stress that the creation of secondary markets for the recovered product is still an intrinsic process of the chain. Apart from these interpretations' deviations, further differences reside only on the terminology used.

Figure 2.1 - Operations' sequence as described in (Joseph D. Blackburn et al., 2004)

Blumberg (2005) in turn proposes a more broad description of reverse logistics in a closed loop system context, regarding it as the integral part responsible not only for the control and handling of the material flows from the field but also for their reintegration in the reprocessing, recycling or disposing phases of the cycle.

de Brito, Marisa P., Dekker (2003), on the other hand, point out the difficulty in defining exactly what raw materials and end users are in a modern supply chain as used products can be used as a source for other productions (e.g. recovered glass is an increasing input in the glass manufacture process), and suggest the concept of closed-loop supply chain, a holistic view on a system combining both forward and reverse supply chains, highlighting the need for the coordination between both streams.

A divergent view, in which a difference between reverse logistics and reverse supply chain is established, is followed by (Gupta 2012). The difference lies on the extension of both concepts, where *"RL mainly deals with transportation, production planning and inventory management"* as opposed to the broader focus of reverse supply chain "*involving additional elements such as coordination and collaboration among channel partners.* That is, reverse logistics is understood as *"one of the elements of a reverse supply chain." (Gupta 2012, p. 22).*

Deriving the sorting process form the type of product recovery, Gupta offers a more in depth interpretation of the reverse supply chain, as can be seen in figure 2.2.

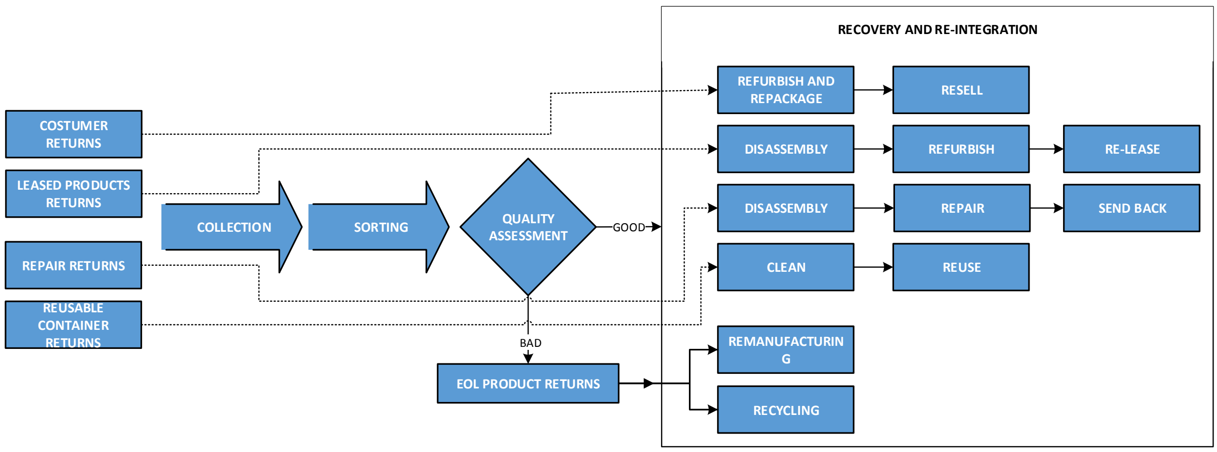


Figure 2.2 - Representation of a reverse supply chain (according to Gupta)

Even though the different types of product returns and transactions between organizations and consumers will be approached throughout this work, this will be done later when analysing different business models. In order to provide a clear understanding a simpler version of the reverse supply chain will be presented here.

It is therefore important to mention that despite all the different considerations and interpretations when approaching the RSC concept, when dissociating the interpretation from the process level into a broader perspective a simpler explanation based on the sequence of the four key steps considered depicted in figure 2.3: product acquisition, testing operations, product recovery and reintegration of the existing forward supply chain.

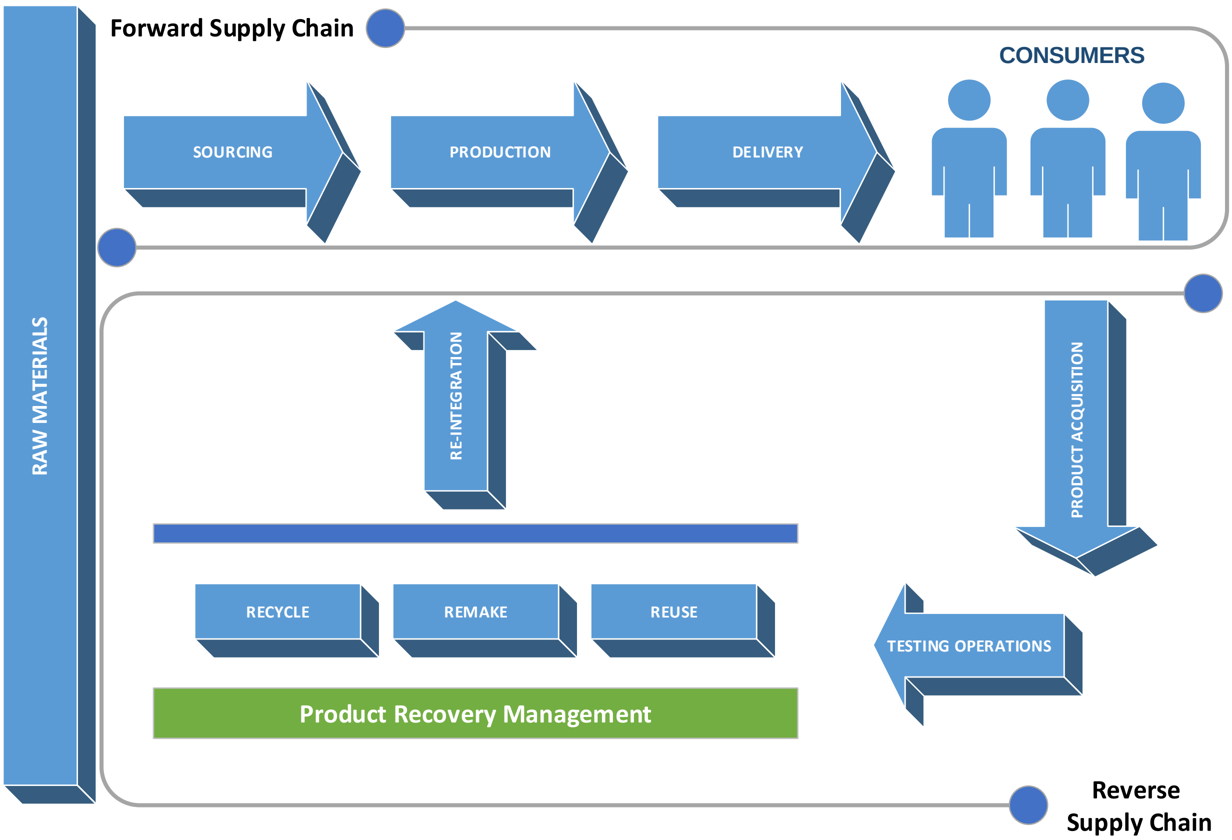


Figure 2.3 - Main operations within a closed loop supply chain

At first, it is important to define the meaning of reverse logistics differentiating it from other literature and using it as a reference for the course of this work, which here is understood as the set of processes needed to handle a product from the point of collection to the sorting including these processes as well. Then the product recovery management process set ensues.

Starting at the collection point, the process comprising the retrieval and the collection of used products from their users is one of the main problems cost-wise as it is comparable to the 'last mile' issue in distribution and transportation networks. That means that the retrieval of a low amount of products from many possible locations will render collection an expensive and consequently ineffective operation (Blackburn et al. 2004). Adding to that effect, there is a particular uncertainty regarding quantity, quality and timing of the end of life product returns.

A solution found by some companies that minimize this issue is partially based on a slight cost sharing between the firm and the customer by installing collection centres or drop points where the used products can be handed and sorted without having to be transported to a centre facility. At these centres, depending on the condition of the product and the return type, a decision is made regarding the disposition strategy. With this assessment the firm interested in setting up a reverse supply chain enters in the product recovery management analysis.

Various and further analysis can be made depending on the reasons for the return of the product (repair, end of life, end of lease and warranty) which will ultimately decide the point of the forward supply chain where it should be reintegrated. If the product wasn't opened it can be sold as new and reintegrated almost immediately in the forward supply chain. In the event of an opened product package, testing operations will ensue to decide if the product can be refurbished and resold as a refurbished product or whenever deemed seriously damaged products regarded as end of life product return. (Gupta 2012)

This means that during this work there will be addressed three recovery options: reuse, remake and recycle, that will define the point of entry of the returned product into the forward supply chain.

Even assuming that refurbishing operations will take place in order to bring them up to a specified quality, the reuse option is clearly the one which reduces the time spent of the reverse logistics network benefiting from the least loss of value since its collection. Although these products will not be sold as new, technologically upgrades can be made by replacing outdated components or entire systems with technological superior ones. This can be usually seen in military equipment and aircraft, where the refurbishing operations expand their service life while and overall quality while still being bought as a used product for a lower cost. (Thierry et al.)

The remake or remanufacturing solution will, instead of upgrading or simply repair the used products, result in new remanufactured products having the same warranty and quality as brand new ones. The disassembled parts are thoroughly inspected and replaced by new ones when deemed outdated or damaged. Although some authors distinguish remanufacturing from the cannibalization option, in which after a selective disassembly a small proportion of the product parts are deemed potentially reusable and retrieved while the rest of the product is recycled or disposed, these two options will be treated as the same as the only variable is the proportion of the retrieved parts.

Both of these options are considered to be the most profitable and environmental friendly recovery options as the reused and remanufactured goods will always retain some original parts and form, which means that not only the material of which the product is made can be recovered as is the case in recycling. In this last option, the aim is to turn the used products into raw material used in the production of new ones.

Apart from the condition of the returned product it is worth mentioning that, the type of the return plays a big role in the decision process. While repair or service returns often spend more time in the reverse supply chain as there is the need to discover why they failed to perform as they should indicating potentially damaged or broken parts that need to be repaired or replaced, end of lease products can, when possible, be immediately re-leased.

This section indicates the organizational structure of both forward supply chain and reverse supply chain with special focus with the phases responsible to collect and handle the product until its reintegration in the forward network. As such focusing anew the reverse supply chain phase, the product after being collected from the original market and sorted according to its remaining value and return condition, a decision is made regarding the recovery procedures taken to reintroduce it into the forward supply chain.

The product may be:

- **reused** without any deep changes in its functional core, being reintroduced in the **deliver phase** of the forward supply chain, FSC,
- **remanufactured** after being dismantled and inspected to differentiate valuable components, modules or parts used to build a new product from non-valuable parts due to disposal, posteriorly reintegrated into the **production phase** of the FSC, or
- **recycled** after being disassembled and each of its components inspected to once again differentiate the non-valuable parts from the valuable ones that are posteriorly reintegrated in the **sourcing phase** as raw materials.

2.2 Business Models

Even though the notion of business models has been implicitly employed in trade and economic behaviour since classical times, the study of its theoretical roots has been linked to the advent and evolution of the internet and the rise of new and rapidly growing markets (David J. Teece 2010).

Since then different views of new business models have appeared, some reflecting the way that revenues are collected, while other based on the exploitation of the supply chain structure and the way value is retained within.

In spite of the existence of different notions of business model, mainly based on the area in which the concept is used, it is easier to identify some key common elements. While most of the available literature assigns the nuclear role of a business model to the definition and explanation of the structure and organisation of a nuclear firm, its relationships with its partners and ultimately the market, describing the network structure of an organisation, the transactions and their management, the revenue generation or the knowledge flow within the network are also used to describe and classify business models.

Another issue found when fully understanding the concept is once again the different perspectives and approaches taken by different authors. The deconstruction of the concept into partial and universal approaches is frequently found in the current literature. In that case a partial model presents particular aspects of a company while a universal one explains the entire business activity of the company where a business model can be adapted into other companies and markets (Becker 2011).

From a larger and broader perspective a business model can be understood as the way in which an organisation does business, that is, it seeks to understand and explain how a company creates and delivers value to its customers and converts the revenue to profit, highlighting the notions of value streams, customer value, value proposition, monetary and financial concepts such as cost structures and revenue streams, and characteristics of the supply chain, namely delivery channels used and relationships with delivery partners. These three main branches form a wider concept of business models and constitute a differentiation basis between business model types. (Zott et al.).

(Osterwalder, Pigneur 2011) aim to establish a concept that "*everyone understands*" and that *"simplifies the discussion and description"* of a company's business model so that *"everyone starts from the same basic principles and communicates about the same concept" (Osterwalder, Pigneur 2011, p. 19).* This is accomplished through the introduction of the Business Model CANVAS, a pragmatic tool comprised of nine basic building blocks that facilitates the analysis, discussion and comprehension of the business model arranged in the manner presented on figure 2.4.

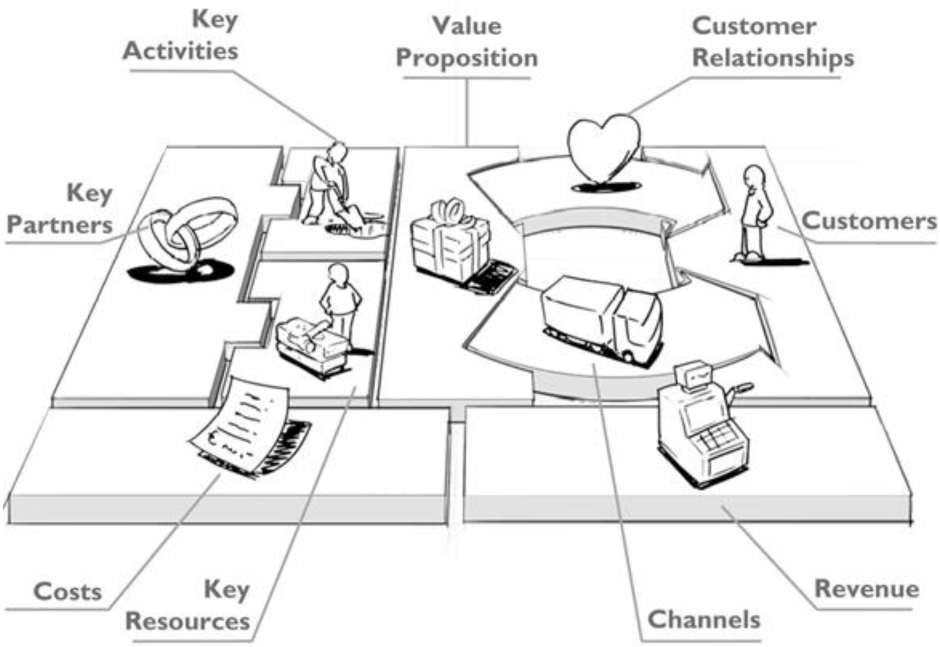


Figure 2.4 - Alexander Osterwalder. 2011. "Business Model CANVAS". *Business Model generation*, page 23, Frankfurt am Main:Campus Verlag GmbH

The core of a business model is often the clients it seeks to reach. As such when designing a business model the consumers should be identified and considered, that is the company must decide who will be handled and who will be ignored.

Therefore the **customer segments**' building block defines the group of people or organizations for whom the company will create value with its products or services. According to (Osterwalder, Pigneur 2011), differentiated groups can be identified , with focus on:

Mass Markets - Business models that aim for mass markets don't differentiate between consumer segments as the goal is to reach the biggest group of potential clients with similar needs as possible, therefore focusing the value-proposition, distribution channels and consumer relationships on the maximum number of consumers as possible.

Niche Markets - The value proposition, distribution channels and consumer relations focus on the specific needs and characteristics of a client. An example can be seen on the dependence of the automotive parts builders on their major client.

Segmented markets - Different consumer groups are established and while both are object of the company's attention, their needs are attended differently. This segmentation can be made according to gender, income as is the case of car manufacturers, age notably made by cosmetic manufacturers or even a hybrid age-income approach, as is the case of mobile and telecom companies. However unlike the diversified customer business model, these customer groups still have the same basic need or problems which are attended by the company.

Diversified markets - An organization with a diversified customer business model serves two non-contiguous customer segments with very different problems and needs.

Multi-sided platforms - These business models aggregate at least two interdependent consumer groups. It is the case of companies that provide services to mutually dependent customer segments, like credit card companies that serve both credit card users and retailers or free newspaper companies that need a large audience to attract advertisement companies.

Under **value proposition** are described the products and services that create value for a consumer segment. That is it is what differentiates one company from another and justifies the consumer decision when choosing one over the other. This differentiation from the competitors can be achieved through innovation, design, price, cost reduction, availability, and convenience among others (Osterwalder, Pigneur 2011).

In a pragmatic approach, the **channels** consist in the contact points between the company and its clients. It describes how the company reaches their customers and which channels are accordingly used. Differentiating between the company owned direct channels, which can offer an increase of the profit margin, and the partner operated indirect channels, that in turn allow not only for an increase of the general coverage and reach of the company but also to profit from the strengths of its partners, Osterwalder, Pigneur also introduce the concept of channel phases, described in table 2.1, that can be partially or completely covered by every business model channel:

Table 2.1 – Chanel phases as (proposed by Osterwalder, Pigneur (2011))

Draw attention	How is the customer's awareness raised towards the product?
Evaluation	How the customers' evaluation of the value-proposition is facilitated?
Purchase	How the product availability for purchase is reached?
Communication	How the value-proposition communication is established?
After Purchase	How is the customer protected after the purchase?

In the **consumer relationships**’ block the type of relations that the company wishes to create and maintain with its customer segments should be identified. What varies in this building block of the business models is the proximity of the relationships between the company and the customers and the effort put into those relations.

While personal service allows the interaction between the client and a customer service representative in order to provide assistance during or after the sale, in the luxury market environment companies will often resort to individual personal assistance in which a sales representative is assigned to respond to a single client’s needs, a self-service approach offers a more indirect relationship in which the company provides the client with all the necessary means the latter needs to satisfy their own necessities. Between these two extreme points, one can refer to an automated service as a compromise point, in which the individual preferences and client characteristics can be recognized and personal record sheet can be established, ideally simulating a personal relation with the customer. A close example of the latter is the individual offers that e-commerce companies are able to provide to their potential customers based on their previous searches or purchases.

Nowadays companies are progressively regarding the relations with communities of clients as a useful method of interaction creating a scenario where feedback of their products or services can be easily and massively obtained as a solution to solve common problems.

Apart from the previously mentioned interactions, the client direct input can help the company in the value creation. These forms of co-partnership are often seen in e-commerce business under the form of product reviews

Under the **revenue sources**' building block the sources of income coming from the different consumer segments are explained. These sources can be developed through the sale of commodities, usage fees frequently used in the telecommunications' field, membership fees, lending fees, renting fees, leasing fees, licensing fees, commission of brokerage fees generated through the intermediation services between two or more parties and advertising fees generated from product or services advertisement. The event or media industries are traditionally dependent on this latter revenue source.

Allowing the company to create and offer value, to sustain relations with and to attain revenues from the different consumer segments, the **key resources** define the necessary assets in the activity of the business models. These can be sorted into physical resources like production or logistic facilities as well as other machines or systems needed in the activity of the company, intellectual resources like the patents or copyrights.

Distinguished among production or problem solving activities as well as platform or network usage disposition, the **key activities**' building block is the representation of what the company must do in order to create value.

The network of suppliers and partners that helps, minimizing risks, acquiring resources or optimizing the business model is named **key partnerships**. These, according to the relationships of the partners and their relative position in the business, can be differentiated into strategic alliances, where the two parties are non-competitors, coopetition (that partnerships formed between two competitors), joint-ventures with the development of new business in sight, or buyer-supplier relations where both parties coexist in the same supply-chain.

Finally all costs that arise from the implementation and execution of the business model are encompassed in the **cost structure** building block. Here is depicted the position of the company toward costs and costs reduction. When the focus is on costs reduction, it is designated as a cost-based business model. If the emphasis is on creating a higher value, regarding the costs reduction as secondary, the business model is categorized as a value-oriented business model. In addition the intentions of the company to explore either economies of scale or economies of scope also feature here.

By re-arranging and regrouping these nine building blocks of the Business Model Canvas, Gassmann et al propose a condensed version based on four different dimensions (Gassmann et al. 2013).

While the first two dimensions, the clients, referring to the consumer segments and value proposition, are analogous to the respective building blocks found in the Business Model

Canvas, the components value chain and revenue mechanism differ slightly from the model previously explained.

The Value Chain depicts the management of the activities and processes engaged by the company to create value proposition in combination with the problem-solving abilities and the required resources and their integration in the value chain constitute the third dimension of the model. This includes previously disaggregated elements such as key activities and resources.

Including the cost structure and the revenue sources, the revenue mechanism explains why the Business Model is viable and how the company creates value.

On the other hand (Becker 2011; Zimmermann 2013) choose to divide the core concept into six other elements: the Product-Market combination which reflects in which markets and with which products the company wants to compete, the configuration and value creation attainability establishing the layout of the value chain, the income mechanic and revenue structure that identifies the income sources as well as the price proposition. The orientation towards competitors locates the competitive position of the company and strategy to deal with its competitors. The resources structure represents the capital or human capacity of the company and the company culture and organization that explains how and by whom the company is managed.

By presenting it as a simplified and aggregated picture of the relevant activities of an organization (Wirtz 2013, p. 3), explaining how the commercialized information, products and services originate from the value creation activities considering not only the architecture of the added value but the client, market and strategic components in order to generate and maintain a competitive advantage, Wirtz further divides the business model structure into three dimensions built by partial models represented in figure 2.5 : the strategic dimension, the client and market dimension and the value creation dimension (Wirtz 2013).

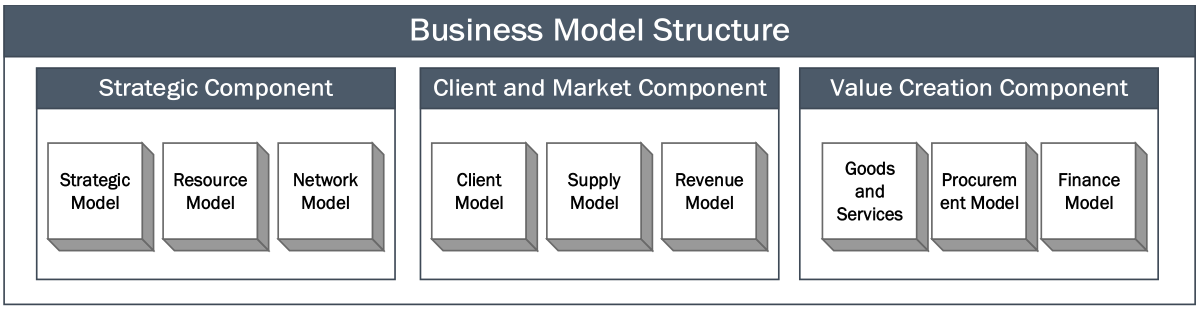


Figure 2.5 – Business model's structure (according to (Wirtz 2013))

The strategic component of the business model is built on top of three structural elements. Divided into four sub dimensions (strategic, business, functional and relationship dimensions) the strategic model clarifies the positioning and development path of the company and the resource model represents the tangible and intangible core assets and competences of the company and the generation of the competitive advantage. On the other hand, the network model explains the partners' interaction and the business model network.

Serving as the connection between the other two components the client and market component depicts the environment in which the company moves. It includes **the client model**, which identifies the target customers or groups and customers' relationships, defines the channel configuration and the customers' contact points optimizing the business model to the clients' needs, **the supply model**, that defines who the competitors and the market structure are as well as the value offering of the products and services, **and the revenue model**, that presents the revenue streams.

Under the influence of the strategic and client and market components, the value creation component focus on how and under which conditions more value can be created. It encompasses the **goods and services partial model** responsible for the explanation of the production of goods and services and for value generation within the company, the **procurement model** explaining the resource and information acquisition and the **finance model** explaining how the company finances its activities, the capital needed and in reserve and which are the underlying costs.

While the current literature is more focused on the establishment of a general and broad business model structure that can be used as a template for any existing or current organization in order to track and evaluate its performance or in the context of innovation to create or enter in new markets, the relevance of the concept to this work is the influence that the chosen revenue sources of a company's business model has on the value chain.

Therefore in the course of this work a simpler business model structure will be considered based on the four dimensions depicted in figure 2.6.

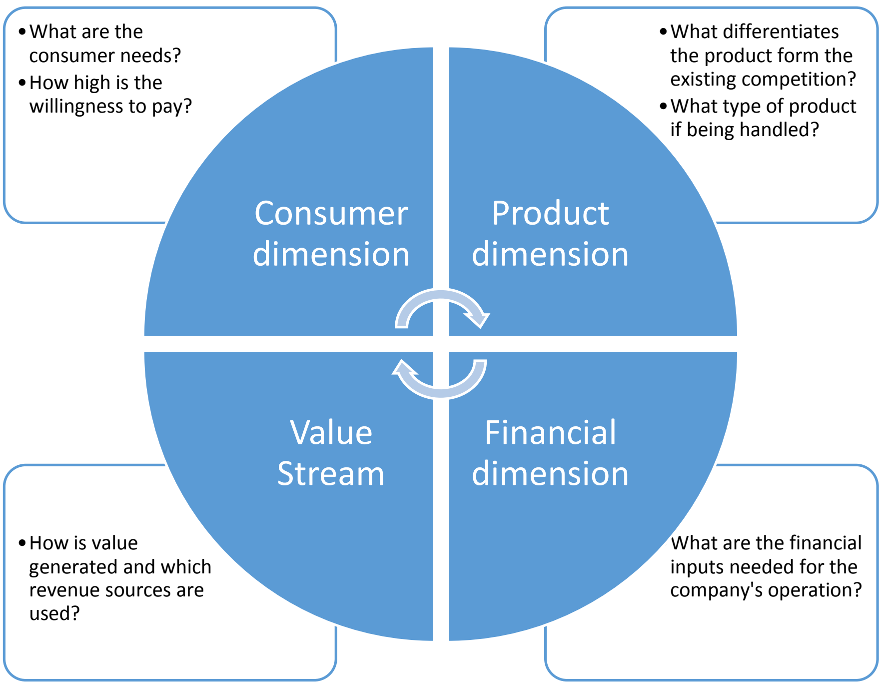


Figure 2.6 - Business Model Framework

In the context of a closed loop supply chain, a number of different business models were considered and analysed by (Blumberg 2005), differentiating basic reverse supply chain business models from closed loop supply chains with various degrees of recovery.

A **basic reverse supply chain model** is here understood to only deal with waste and unwanted materials, operating independently from the direct supply chain. The emphasis is then given to an economic disposal and consequently on the reduction of the costs related to the reverse logistic activities and the residual economic value of the returns is not considered.

In the course of this work there will be a significant deviation from this explanation as the approach to the reverse supply chain will be made in a closed loop system with the intent of evaluating the performance of RSC focused not only on a cost effective disposal but on the potential recovery of the residual value and further reintegration of the product.

As such, during the course of this work the relevant business models in a reverse supply chain context will be highlighted and explained in more detail in an effort to compare and evaluate different approaches that could be studied by an organisation.

3 State of the Art

In the previous chapter the concepts of reverse supply chain have been presented, encompassing all activities necessary to recover products from the consumer followed by their reintegration on the forward logistics network, and business models as the way a company creates and retains value. A reverse supply chain business model would therefore be encompassed by the measures taken by a company to create value from previously discarded products by remanufacturing, recycling or reusing them retaining some of the remaining value. Both these concepts will be further mentioned and will be subject of more specific explanations throughout the work as needed to understand the basis for their simulation.

Therefore the relevance of this chapter is based on the need to introduce the existing work and research regarding the evaluation and simulations of Business Models and reverse supply chain, differentiating different research approaches, in order to later depart the evaluation model from existing ones.

3.1 Simulation approaches for Business Models

Organizations wishing to venture in new markets need a tool capable to emulate the development of the target markets and its causes. In the scope of this project, a company who seeks to implement a reverse supply chain needs to fully understand the characteristics of the secondary market, the potential competition they will be faced with and the driving forces behind the engagement in recovery activities as well as the eventual benefits reaped from selling, leasing or renting options and their respective costs.

The qualitative analysis regarding business models is described to be very low and limited to small and medium sized enterprises (Zimmermann 2013). However a various number of simulation methods can be modelled according to the business model planner needs.

A static assessment tools as the SWOT analysis, the Porter’s five forces analysis or PEST analysis are already frequently and globally used tools to assess the potential risks inherent to a particular business model predicting business and market behaviours.

However, when addressing the dynamic and complex reality intrinsic to a business model, a dynamic simulation tool allows for quicker explorations of a wider pool of scenarios. Its goal is the prediction of errors or faulty decisions and their correction without the costs associated to an actual business failure and a faster detection of these errors. Commonly used methods involve the Monte Carlo simulation, stochastic investment models, agent based simulation, scenario-based simulation, discrete event simulation or a combination of two or more of the previous methods.

Often used to model uncertainty, randomness or risk scenarios associated with market variations or, in the context of reverse supply systems, the uncertainty associated with the returns’ collection, the Monte Carlo simulation is based on a previously established deterministic model. After the determination of the statistical distribution from where the inputs parameters are drawn, the random samples are generated, that is a set of random values that represent specific values of the variable considered are randomly selected, and used in the deterministic model generating one set of outputs that are then subject to a statistical analysis.

Used frequently in finance to capture the net present value, in portfolio evaluation aiming to model the value at risk or in reliability analysis, this method comes into relevance in the context of supply chain management for its usefulness when modelling uncertainties. (Raychaudhuri 2008)

Schmitt et al. discuss the impact of disruptions and the quantification of the dynamic nature of the associated with the risks within a multi echelon supply chain, which was simulated through the combination of Discrete Event Simulation (DES), employed to set the model of flows and interactions between different agents in the supply chain, and Monte Carlo simulation, used to create and quantify the risk profile of each interaction between agents (Schmitt et al. 2009).

Before the introduction of the risk factor and the disruptions in the simulation model, a base model set around the proposed network flow consisting of a single manufacturer, a packaging plant and three distribution centres was simulated and validated. The Monte Carlo method is then used to create a risk profile in every contact point between the intervening agents, testing possible disruption mitigation strategies.

The discrete-event simulation method is a recurring iterative method in operations research (Jacobson, Yucesan 2002) that seeks to either maximize or minimize the value of a pre-defined objective function. The modelled system is described by a set of states, numeric values that characterize the system's elements, and events that occur at a defined time instant and induce transitions between two different states.

It should be noted that this method is also recurrent in the context of supply chain simulation and will be further mentioned in the following section.

Another simulation method is worthy of mention due to its recurring appearance in the network management context. Consisting of a bottom-up approach (Sichman et al. 1998, p. 61), the agent-based simulation is used to model interactions between independent agents. A study of the management of renewable resources made by Sichman et al. is based on the lastly mentioned method allowing the simulation of local interactions between agents that occupy different positions in the industry from the harvester to the final transformer in a centralised and a decentralised models. This simulation approach allows the definition of individual behaviours which are based on individual profit maximization. The centralised model is defined by a price proposition mechanism that balances the demand and supply of the whole chain, while the decentralised model sets the commodities' prices as a consequence of the individual interactions between agents. After the resources and agents' behaviour are modelled, the prices are calculated through a global equilibrium principle seeking for the price that leads to the balance of the supply and demand of the agents at each stage or through the local trade principle based on the geometrical mean of the buyer and seller's marginal rate of substitution. Aiming to explore the influence of taxes and trading quotas in such supply chain, eight scenarios are simulated, ranging from local trade without taxes nor quotas to a global equilibrium trade with a 20% tax applied to the harvesters and first transformers and a 25 resource units quota scenarios.

To assess the market share of electric vehicles in a determined area and based on input data published by government and research organisations concerning demographics, economic data and consumer behaviour Komoto et al. develop a quantitative evaluation of an integrated scenario model composed of multiple sub-scenarios that themselves represent the demographic and economic evolution pertaining a determined area, the products life-cycle, fuel and electricity prices, previous sales volume of electric vehicles and other hybrid variants (Komoto et al. 2013). This is made through the integration and the definition of the relationships between these former scenario indexes and the performance progress and market data regarding electric vehicles from 2011 through 2030. The resulting discrete variations of the sales volume respecting different countries, see figure 3.1, allows a comparison between the pre-established wealthy countries' group and developing country's one as well as the influence that the initial parameters have in the resulting market share.

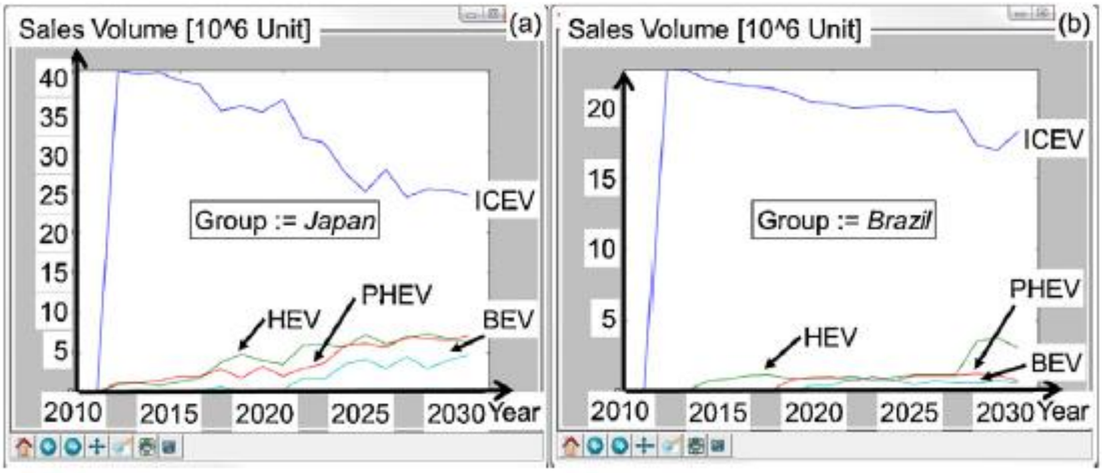


Figure 3.1 - Komoto et al. 2013. "Simulated sales volumes of specific countries". *Quantitative scenario-based simulation of global business models for manufacturers*. Elsevier

3.2 Evaluation of Reverse Supply Chains

In this section it will be explained one critical issue in supply chain management and by extension reverse supply chain management: its performance evaluation.

Various methodologies have been put into practice when analysing generic supply chains.

Ming et al. make use of game theory to evaluate the effectiveness and competitiveness of supply chains in a supply chain vs supply chain competition (Ming et al. 2007).

Tao purposes an alternative evaluation method based on fuzzy matter-element theory, in which six different supply chains are analysed. A number of performance indicators are individually evaluated and sorted into the following four categories: satisfaction degree of the customer, information sharing degree, logistics level and financial conditions. The indexes weights of these indicators are then determined in order to construct an evaluation index system that represents the coordination, stability and sustainability of supply chains. Then an approach degree is calculated which reflects the closeness of a supply chain to the standard one to be used as the evaluation criteria. However deviations can be identified when using this method, as the indexes weights are usually determined through subjective models (Tao 2009).

In the service supply chains' context, (Song et al.) suggest the use of a hybrid solution between the data envelopment analysis (DEA) and analytic hierarchy process (AHP) methods which solves both the lack of flexibility of the first method which can only deem the decision making unit (DMU) to be efficient or inefficient and the subjective preference present on the latter ((Song et al.) 2008).

Furthermore, the reliability of a supply chain was addressed by Cao et al. using a back propagation (BP) neural network by assigning each of its members a reliability index based on client-oriented indicators, internal indicators for enterprises and reliability coordination indicators (Cao et al. 2008).

The agent-based simulation approach is used to analyse the global performance and the interaction between partners integrated in the same network but with different inventory, production, procurement and shipment politics (Seco, Vieira 2014). The ratio between the total quantity sold from shelf and the total quantity ordered is the measure chosen to evaluate six different collaborative polices along the network.

While a plethora of methodologies is available for the evaluation of forward supply chains, the existing research conducted on reverse supply chains' evaluations is still scarce and reverts to simulation-based methods, which will be introduced later.

However because, as it was explained in previous chapters, the waste management and value recovery of returned products has now been seen by some companies as a way to gain competitive advantage over rival companies, the crucial assessment when considering engaging on a RSC initiative it's its performance. An effective performance management is therefore an important aspect of the RSC initiative and the key to recognize the benefits of efficient supply chain management systems.

In addition to the vast criteria already involved in an evaluation of a forward supply chain turning it into one of the most complicated problems in the decision making process, the annexation of a reverse supply chain or purely its isolated examination presents an even greater challenge due to the inclusion of further variables that increase the uncertainty level of the value and material flows namely, the return rates, volume and timing, remanufacture rate among others.

As such, to seek a full understanding of the recent performance evaluation approaches and differentiating between qualitative and simulation-based approaches, a few methods to measure the performance of supply chains will be introduced, analysed and compared. It should be noted that despite appearing in different sections both research methods are not mutual exclusive, in fact both seek to achieve different results and can be used simultaneously in order to complement each method's weaknesses in addressing a particular problem and metrics used in both systems can be adapted in the case of a mixed method research that uses both qualitative and quantitative data to answer the research questions, through the means of qualitisation of quantitative data and quantitisation of qualitative data. (Saunders et al. 2012)

3.2.1 Qualitative Approaches

The qualitative approach involves a generation of a new theory from observations and interpretation of mainly non-numerical or sometimes unquantifiable data gathered. It seeks the intensification of the research's focus, as detailed as possible, on a particular situation and the full description of the phenomenon in hand. The information is generally gathered under the form of interviews, focus groups, observations or case studies, which due to the unregulated data collection techniques, variability of the data and the uniqueness of each case renders this research type both time consuming and very specific in the sense that the final output cannot be generalized to the whole population.

As such, these investigation methods are useful for giving an insight and complete understanding of a specific problem in addition to its theoretic background. It provides the opportunity to reveal and understand the perspective, attitudes of the relevant participants and partners within the reverse supply chain and the context in which they are inserted. This allows an analysis from an insider perspective, and the conceptual understanding of the links and relations between partners and the customers' behaviour patterns.

However the nature of the empirical and subjective data obtained from conclusions or observations of the participants or researchers reveals the subjectivity of this kind of analysis, maintaining nonetheless a flexibility adapting to eventual additions of future gathered data or conceptual changes.

Based on the impossibility to isolate it from its social implications and complexity and from its temporal and local context as well as grounded on the need to consider multiple subjective viewpoints, Gobbi conducts an investigation regarding the configuration, integration and profitability of the reverse supply chain through a qualitative based methodology (Gobbi 2008).

To that end, three research questions are proposed:

Question 1: Which are the factors considered when configuring a reverse supply chain?

Question 2: Which factors allow integration between reverse and forward supply chains?

Question 3: Which are the conditions for a profitable reverse flow?

As the goal of this section is assessing the existing methodologies and researches regarding the evaluation of reverse supply chains, the focus will be given to the answer of the third research question.

To answer this question a query is proposed consisting of the following questions:

- Why is product recovery an opportunity for generation of profit and what are the key factors involved?
- How can the performance of a reverse supply chain be measured and which metrics can be applied?

To that end the following propositions are approached:

Proposition 1: Influenced by the supply chain structure the profitability increases when the optimal reverse network model design is implemented allowing the extraction of most of the total residual value of the returned products.

Proposition 2: It is assumed that profitability of the reverse supply chain, its integration in a forward chain and the involvement of the OEM are correlated.

After the initial research protocol has been set, the research bases itself on two case studies that analyse a legislation (LDRC) and a value driven reverse chains (VDRC), one interviews to relevant actors participating in the reverse process. For specifics on both study cases, refer to (Gobbi 2008, pp. 99–121)

In both instances the engagement in reverse supply chain activities is deemed profitable for at least one agent in the reverse network. In one hand the logistic providers and recycling companies benefit from a LDRC, in other hand the analysed VDRC is profitable for both the logistics provider and the producer.

The profitability of the reverse chain is assessed through a quantification model with the help of a number of metrics, namely total the quantity of products and their return rate, the percentage of returns suitable for reconditioning, the costs limit set by the customer, the reconditioning, transportation and disposing costs and the prices of reconditioned and remarketed products.

The chain is then deemed profitable for the recycling company and service provider if

$$Price_{reconditioned} > \frac{Cost_{transportation} + \%_{leasedproducts}\left(Cost_{reconditioning} - Cost_{disposal}\right) + Cost_{disposal}}{\%_{leasedproducts}}$$

and for the producer if the remarketed products are sold at a higher value than the reconditioned ones, providing it does not exceed the price accepted by the consumer.

In an effort to provide a standard evaluation tool for supply chain performance, the APICS Supply Chain Council (SCC) a global organization proposed the **SCOR framework** for evaluating and comparing supply chain activities and performance, enabling the analysis of "*supply chains, whether simple or complex, using process building blocks and a common set of definitions*" (SCOR Framework - The APICS Supply Chain Council).

This framework is composed of a modelling tool built upon regulated standard processes, key performance indicators and a benchmarking tool to enable comparison between different supply chains and companies.

The processes are standardized and defined according to three hierarchical levels with growing specification and depth. As such, a level one process is composed by the aggregate of its related sub-processes from lower levels.

The first level depicted in figure 3.2 consists of five core process types and seeks to define them.

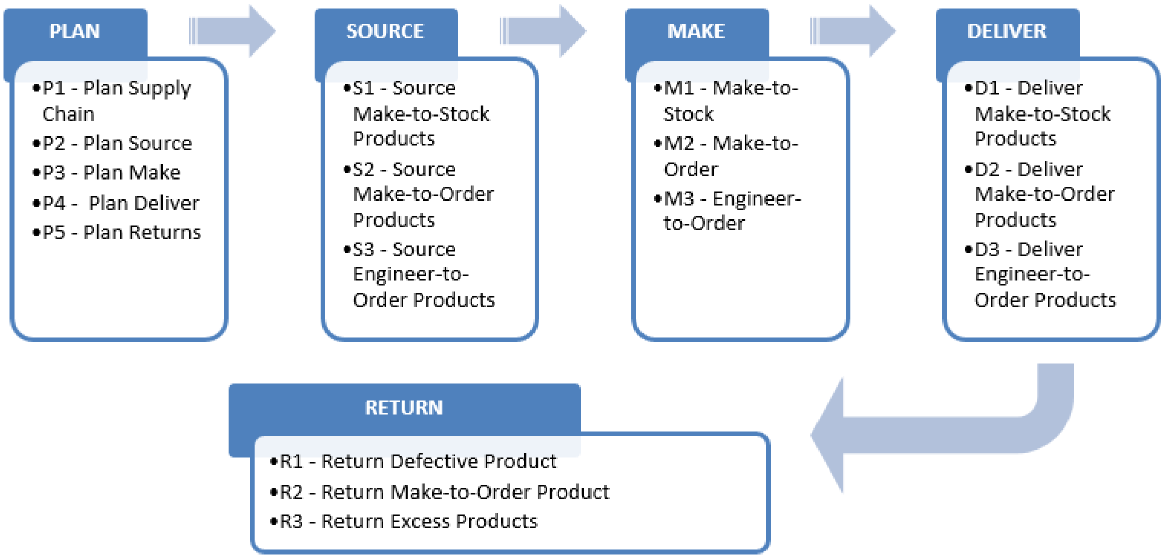


Figure 3.2 – Process levels 1 and 2 of the SCOR model framework

The plan processes assess supply resources, plan inventories, production and material requirements. The source processes deal with procurement and inspection of raw material and finished goods. The make processes handle the request and material reception, the product production and testing as well as its packaging and release. Meanwhile the deliver definition approaches the transportation management processes, warehousing, product shipment and performance evaluation. Finally the return processes handle the returned products' inspection, scheduling and defective products verification and replacement (Umeda 2013).

The level two consists in a more in depth and specific approach to the five core process definitions. Here the model distinguishes between make-to-stock (MTS), make-to-order (MTO) and engineer-to-order (ETO) products.

The third level further decomposes the process types present in level two into process categories, for instance, the S2 (Source Make-to-Order product) is decomposed into the schedule product deliveries (S2.1), receive product (S2.2), verify product (S2.3), transfer product (S2.4) and authorize supplier payment (S2.5).

Accompanying this standard business process categorization, the SCOR model also defines two sorts of performance attributes each containing a set of metrics that similarly to the processes classification seen above can be further divided in lower levels.

These performance attributes are divided in **customer facing performance attributes**: reliability, responsiveness and flexibility, and **internal facing attributes**: costs and assets.

Table 3.1 shows the tier one metrics linked to each of the performance attributes.

Table 3.1 - Performance measurement attributes and level one metrics based on the SCOR model

	Performance Attribute	Level 1 performance metrics	Definition
Customer Facing attributes	**Reliability**	Delivery Performance Fill Rates Perfect Order Fulfilment	Percentage of orders meeting delivery specification within time and without damage
	Responsiveness	Order Fulfilment Lead Times	The cycle time achieved to provide the customer the acquired product products to the customer
	Flexibility	Supply Chain Response Time Production Flexibility	The agility of the supply chain and its reaction to market changes
Internal Facing Attributes	**Costs**	Cost of Goods Sold Total Supply Chain Management Costs Value-Added Productivity Warranty/Returns Processing Costs	All expenses associated to the operation of the supply chain based on the SCOR framework
	Assets	Cash-to-Cash Cycle Time Inventory Days of Supply Asset Turns	The assets management in order to support demand satisfaction including fixed and working capital

Finally, based on level one metric data, the benchmarking tool provided in the SCOR model allows a company to compare the performance of the supply chain with other supply chains in similar industries.

3.2.2 Simulation-based approaches

In contrast to the qualitative evaluation approach, the quantitative approach to the evaluation of reverse supply chains is objective, collecting numerical information with the goal of producing numerical outputs. Its usefulness resides on the possibility to quantify variations as well as the generalization of the result, deemed impossible by the interpretation of results in a qualitative research context.

These methods will be embodied by a simulation-based approach to the evaluation of reverse supply chains, which in essence is nothing more than the applications of quantitative models, retrieving numerical results from also numerical inputs after some initial considerations and some scenarios have been established. The advantages concerning the use of a simulation-based research is the possibility to establish hypothetical scenarios and analyse the system’s behaviour. Thus simulations have been used to solve operational decision making problems such as resource and capacity planning, supplier selection and outsourcing planning (Umeda 2013).

A first stage in simulation research of reverse supply chain based on discrete event simulation is proposed by (Umeda 2013). The goal is to provide a test bed for the implementation of simulation models regarding product reuse in Push- and Pull-type reverse supply chains represented in figure 3.3 (Umeda 2013).

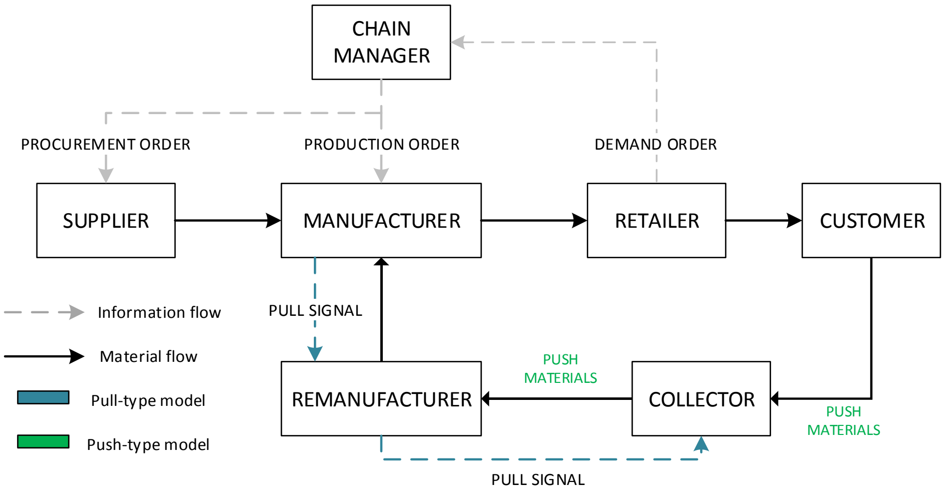


Figure 3.3 - Push and Pull-type Reverse Supply Chain models

In the push driven model the collector and remanufacturer deliver the returned products to the manufacturer according to a pre-established command. In the pull-type model the returned goods acquisition is translated into an inventory management problem where the remanufacturer can be seen as nothing more than a supplier of remanufactured goods, spare parts or recycled raw materials.

The role of the chain manager in this reverse supply chain generic model is to predict the market demand using the exponential smoothing method as well as accordingly issue production or procurement orders to the manufacturers and suppliers respectively.

The performance measuring parameters proposed by (Umeda) are the collection rate of reusable materials, lead-time and lot-size of chain members (Umeda 2013).

In a 20 period simulation two different scenarios are analysed by assuming the collection rate as a high level value (60%) in the first case and as a low level value (20%) in the second one and the respective material inventories' transition between the collector, remanufacturer and manufacturer in both model types are evaluated.

The simulation results exhibit an expected progressive growth of inventories of the collectors in the pull-type models, which have to wait for the replenishment order of the remanufacturers and manufacturers. As such, the inventory levels of the manufacturer are kept in an almost constant level while the inventory volumes in the remanufacturer show an upward trend as time progresses.

As such the pull-type model can be characterised for its particularity of allowing a better control of the number of products collected (providing that no external factors as existing legislation renders the activities mandatory).

In contrast the push systems show a much smaller fluctuation of both the reverse suppliers' inventories (collector and remanufacturer) while the input material in the Manufacturer increases as result of continuous processing of returned products while supply continues.

The material and money flows (MMF) in a supply chain model are the base of another discrete event simulation-based evaluation of a closed loop supply chain by Murayama et al. with the goal of evaluating whether the company engagement in recovery activities is profitable, how heavy the impact is on the environment entailed by such engagement and if the capacity available is enough to deal with such activities (Murayama et al., 2003).

To this effect three partial models were built as represented in figure 3.4: **the material flow** model represents the movement of products, parts or raw material throughout the supply chain; **the money flow** model represents the transactions between different partners in the supply chain and the **flow control model** which deals with information flows which will trigger and control the previous two.

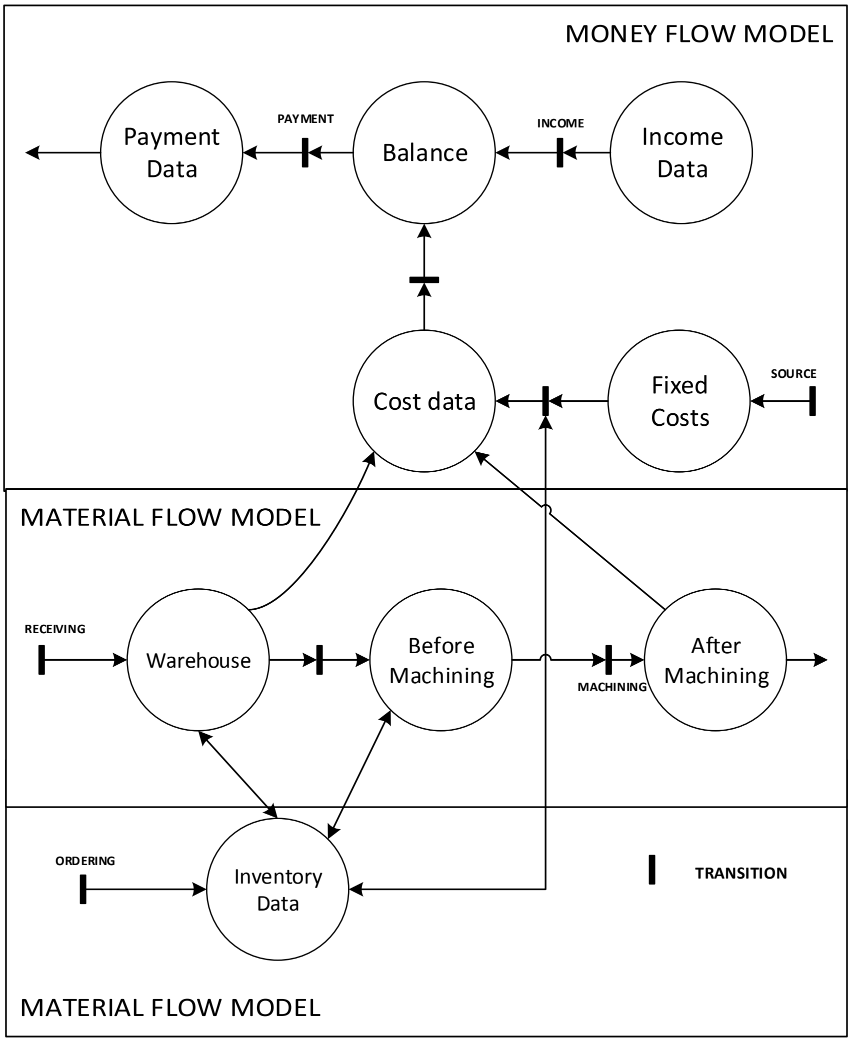


Figure 3.4 - Partial MMF model representation of a participant in the network

Expressing the transaction of data, each transition triggers the update of the data stored in each element of the module, expressing the exchange of materials, money or data transactions in the material model flow, money model flow and flow control model respectively. The interconnection between these modules related to each member of the network means that when a payment is due from a company of the network will trigger a modification of the element payment data in the money flow model of said company which in turn will generate a change in the income data element in the money flow model of another partner in the following state, updating both companies' balance element accordingly.

The profitability is then evaluated based on the evolution of the balance element of each member of the chain providing information of the sustainability of the network in the whole as well as its individual members.

To calculate the environmental load of the supply chain a life cycle assessment is carried out. In every state transition in the material flow model, the requirements for the production or movement of products, parts or raw materials and its outputs are updated in accordance with unitary expenditure and the volume required. The accumulated quantity of each output and input necessary are the performance indicators of the environmental impact of the chain.

(Murayama et al. also take into consideration the different locations of supply chain components namely manufacturers, dismantlers and recyclers, grouping them into considered regions. Thus it is possible to conduct an analysis and redesign of the supply chain based on the regional impacts the network might have, shifting some components of the supply chain from heavily stressed areas into more lightly or unused ones or into ones that present higher economic benefits originating from reduced disposal fees (Murayama et al., 2003).

(Fleischmann 2001) introduce the commonly used methods for the evaluation and design of reverse supply chains and contextualized examples. Although these models focus mainly on the reverse logistics network design, they will be mentioned as they illustrate recent approaches to quantitative evaluations of reverse supply chains (Moritz Fleischmann 2001).

Mixed integer linear programming (MILP) is referred to be the base of most models existing, being frequently used to analyse and minimize the overall costs throughout the reverse supply chain to determine optimal facilities' locations.

A multi-stage stochastic programming model is also mentioned introducing imperfect information regarding of supply and demand in a recycling network. To solve the need for installation of both expensive treatment facilities and locally installed depots a multi-level capacitated facility location model is developed.

Modelling the demand as a continuous geographic density function as solving the lack of focus on the supply uncertainty, referred in chapter 2 as one of the biggest issues when establishing a RSC, from the discrete approaches of the previously mentioned MILP methods, it is suggested a continuous approximation methodology to establish a cost model for a reverse logistics network.

On this model it is considered that two different situations can occur: a centralized or decentralized testing and sorting processes which will in turn generate two different cost assertions.

Based on a comparisson between the costs of a centraly testing and a localy testing RSCs, a break even point is identified establishing the critical distance up to where the central testing option is preferable, the optimal size of the different testing facilities is found and the value of the total cost of the RSC is reached.

Although this model relaxes inventory and vehicle capacity considerations it is usefull to identify existing trade-offs whithin a reverse logistics network between logistic costs, production costs savings and additional revenues.

In this chapter was presented the current state of affairs regarding business models simulation and reverse supply chain evaluation as well as different and complementing available research methods.

A few static assessment methods (SWOT, Porter's Five Forces and PERT) were mentioned due to their importance and relevance in a rapid evaluation of simple of global systems.

In addition several simulation methods were described and briefly explained, with emphasis to discrete-event simulation, agent-based simulation and Monte Carlo simulation due to their recurring usage in the available literature, in order to provide a comprehension of the current available research and contextualise the need to implement a more dynamic suitable evaluation system capable of dealing with the increasing complexity inherent to reverse supply chains business models.

4 Framework

In this chapter the considerations pertaining the influential agents and events existing in a reverse supply chain simulation model will be described and explained, namely the influencing factors and their significance for the different business models studied, as well as the methodology used to evaluate the performance of each business model type through the key performance indicators considered.

Additionally each business model type is considered and examples of their application are given in order to contextualize their respective importance.

4.1 Influencing Factors

Due to the wear of products by their use or by the simple passage of time, their value decreases after the initial purchase. The **residual value** of a product expresses the depreciation of a product after its service life or, in the context of reverse supply chains, the value of the product after its collection and before remanufacturing activities take place. As such, it depends on a number of factors, namely the usage given to the product in question, its original market value, expected service life, new technological developments and the existence of markets for used products. Whereas a high remaining product value of a returned product usually translates into easy and profitable recovery activities, however, depending on the business model in question, an intermediate residual value often implies bigger handling and recovery costs, namely upgrading and remanufacturing costs. However, depending on the business model type in question, the acquisition of a higher valued product and its inherent collection uncertainties are evidently higher. The manufacturer faces then a trade-off situation where a higher investment for higher quality returns will secure higher revenues pertaining the recovered products but also an unsteadier income flow of units.

Another influencing factor considered is the **willingness to pay**. By willingness to pay it is understood the value of goods or services that the consumer is willing to exchange in order to procure a service or a product provided by the company. This value depends not only on the perceived economic value and utility of the good or service exchanged but on the alternatives available as well. In a scenario dictated lack of alternatives or their unawareness by the customer, the highest price the latter is willing to give equals the utility of the product and is referred to as the reservation price. When this reservation price is higher than the economic value of an alternative offer, the highest acceptable price equals the economic value of the product (Breidert 2006, p. 27). In the context of a reverse supply chain focused on resources sustainability and environmental protection, the consumer’s willingness to pay translates the readiness to accept a rise in the price of a product so that collection and recovery activities can be successfully implemented.

As the recovery options’ profit is mainly based on the cost savings it generates, the **price of raw materials** is another important factor in the assessment of a reverse supply chain performance as it determines the viability of the recovery of returned goods. Heavily dependent on the material scarcity its influence is measured not only on the total production price but on the revenues acquired from the recycled materials sales or the cost savings generated by their reintegration in the forward supply chain which means that it plays an important role on the decision relative to whether or not a material should be recovered. Its influence on the reverse supply chain depends however on the business model type in question, being highly relevant in business models featuring recycling processes and less so in reusing or re-lease approaches.

Also other operational costs like the **quality costs** or **logistic costs** are relevant factors when accessing the performance of a supply chain.

Relative to the first ones, assuming that prevention costs do not fluctuate between two different business model types, as it is understood that inspections and quality control activities prior to the sale point are the same for every business model, it becomes decision factor when considering the quality of returned good and the dependence of the refurbishing or remanufacturing costs on this factor.

As for the latter the different impact intensity of the logistic costs on the different reverse supply chain business model, mostly felt in the collection stage, depending on the collection system in practise and on the ability of avoiding large stock quantities turn it into a decision factor regarding a supply performance measurement.

The **usage intensity** is used to assess the state of the returned good and which refurbishment operations should or not ensue aiming to recover most of the returned product’s value. In cases of extremely high usage intensity meaning costly recovery operations the disposal of the product is made in the collection point. This factor complements the residual value in the classification of a returned good.

Lastly relevant for business models based on fixed time terms, namely leasing or renting options, the **number of contracts** made by an organization directly reflects the income sources and lifecycle overarching revenues being thus crucial for the evaluation of the reverse supply chain business model.

4.2 Business Models for Reverse Supply Chains

Throughout the development and design stages of the project, six business model types that shape the overall structure of reverse supply chains were considered so that different engagements in recovery activities could be differentiated based on influences of the parameters discussed in the previous section.

In the following sections, these business models are categorized and described according to the four dimensions definition of business models presented on chapter 2.2 and some considerations regarding their implementation in the simulation model developed will be contextually explained.

The implications of their implementation in the evaluation model are later discussed in section 5.2

4.2.1 Leasing and Recycling

The leasing and recycling business model type is based on a leasing contract in which the owner or manufacturer grants a second party, the lesser or in the case of consumer goods the consumer, the rights to use a product for an agreed and fixed period of time known as the lease term, usually pertaining more than one year(Brockhaus-Enzyklopädie 2006), without however conceding any property claim rights. This means that the product continues being a legal and economic possession of the OEM and is due to be returned in the end of the contract or extended for another tenure determined by a new leasing contract.

The distribution of risk and rewards latent in this type of contract depends on the lease agreement signed. If the lessee is able to collect the rewards of an eventual appreciation through a concession of a buying option over the remaining value by the lessor, the latter supports the risks associated with the uncertainty related to the execution or non-execution of such privilege. These privileges can however be, depending on the agreement made, on the side of the lessor which after the lease term is able to exploit the eventual appreciation (Brockhaus-Enzyklopädie 2006, p. 464).

The condition of the leased property is responsibility of the lessee during the lease tenure which can be granted rights to modify or adapt the product within pre-established limits (Östlin et al. 2008, p. 6). Some provisions can also be made considering the repair, maintenance or upgrading of the products by the manufacturer during their lease terms. This in combination with the time limited or frequently revised lease terms shields the customer from obsolescence risks.

The customer relationships pertaining to this business model type are close, as a consequence of the duration of the contract as well as these cooperation considerations between the lessor and lesser.

Two considerations considering the returned products collection in this business model type are worth a mention:

- First both the collection moment and the quantity of leased products collected is well known by the manufacturer as a result of the impossibility to cancel or interrupt the leasing contract during its term, thus the collection uncertainty related to this business model is considered non-existent.
- Secondly, the collection system, whether we are presented with a pick-up or a bring collection system, are only specified by the contract agreement.

The value recovery option present in this business model is the recycling that can be result of resource scarcity and accordingly increasing raw material prices, environmental or legislative measures or of strategic branding decisions aiming for a differentiated presence in the market under a green image label.

After collection, the product is dismantled and inspected in the sorting phase of the reverse supply chain in order to isolate the components which still have a remaining value from the one which recycling is not an option, either due to economic, environmental or legislative concerns.

The materials recycled after collection constitute a revenue source in the form of cost savings in raw material acquisition, that are represented by the revenues pertaining to the sales of the raw materials recovered.

4.2.2 Renting and Reuse

Very similar to a leasing agreement discussed in the previous section, the renting contract, in which the second studied business model type is based, is nothing more than lease agreement, differing only in its duration. These contracts are characterised by their shorter terms that allow the customer a higher flexibility when pondering the termination of a product’s usage and are more suitable, short and sporadic needs or to respond to seasonal dependent demands.

As a result of the short-term agreement concerning this business model type, the reuse option is the most interesting recovery solution to study.

The collection moment pertaining this business model type is marked by a higher uncertainty related to the collection moment when compared to the lease agreement option as the rent contracts revision periods are shorter.

After collection, the product undergoes cleaning and inspection operations in order to assure the functional quality of the return. Depending on the intended quality inherent to the reused product, which in turn depends on the secondary market demand, the product can undergo minor upgrading operations, and however no dismantling operations ensue. After this minor refurbishment, the product is re-rented to another customer and the cycle resumes until the product remaining value becomes too low and the resulting upgrading costs too high rending this business model unprofitable, in which point the product is removed from the market, being either disposed, recycled or remanufactured into a new product.

The business models of the rental services of the German automobile manufacturers Daimler AG and BMW, Mercedes-Benz Rent and BMW Rent respectively, are examples of this business model type. Both provide a vehicle for short periods of time (Mercedes-Benz Rent enables the usage of a vehicle for a day or weekend whereas the minimum tenure regarding the BMW service is one month) and feature distinct collection polices: Daimler resorts to a bring collection system where the vehicle must be returned to the station it was rented from allowing a cost and subsequently a price reduction while BMW focus on the customer convenience resorting to a pick-up collection system retrieving the vehicle from a previously agree location in a pre-settled time, incurring however in higher collection costs.

Due to very short agreement term associated with both these business models and a relatively high service lives of the products when compared with other common consumer products, namely electric and electronic products, the influence of the usage duration in this case considered to be the rental term is small enough to consider the differences between the original and secondary market non-existent. This means that the renting fee applied to the first customer will be applied to the following customers without relevant changes until the product remaining value drops to a reference point or the product is considered obsolete. This does however mean that both companies must incur in cleaning and inspection operations immediately after the return of the vehicle to assure the same service quality to every customer varying the degree of such operations with respective the rent term (BMW Erleben : Mieten; Mercedes-Benz Rent - Mieten Sie den Mercedes Ihrer Wahl. 2015).

4.2.3 Deposit-based and Remanufacturing

Common in the automotive industry the deposit based sale pertains a product transaction in which a caution formerly paid by the customer during the purchase of a remanufactured product is returned after the reception of another used product creating a theoretic 1:1 ratio between the returned products and the remanufactured products demand (Östlin et al. 2008, p. 5).

This agreement sees a mutual benefit of both parties of this agreement’s relationship. The customer profits from products offered for reduced prices as he acts as the used products supplier of the manufacturer. The latter sees this incoming flow of spare parts or whole components as a revenue income, under the form of cost savings regarding this time the raw materials procurement and component production, depending once more on the disassembly index and on the remanufacturing index. This agreement also enables the customer to acquire a remanufactured product the moment an old one is returned, maintaining functionality, important aspect for business to business relationships (Östlin et al. 2008, p. 5).

The aforementioned ratio is however the best case scenario, as failures on product returns as well as the economic unfeasibility of recovering returns in bad condition mean that the manufacturer still relies on its own production and raw material acquisition to maintain its operations. Additionally the strategic decision of the deposit size plays a major role in the performance of this business model. While a low deposit level translates into a low collection rate and consequently high percentage of used products removed from the supply chain, a high deposit will in turn mean either a small profit margin or a big draw on capital for collection purposes.

Following the collection, the product is dismantled in the sorting phase of reverse supply chain in order to, depending on the disassembly index, individually test every component and module. After inspection, the obsolete components are later substituted and redirected to the disposal operations, while the still functional and valuable parts that will undergo value recovery operations generate a new product that will posteriorly be sold in the original market resetting product remaining value and generating revenues under the form of cost savings.

4.2.4 Buy-back and Remanufacturing

Similar to the last described business model the buy-back to remanufacture business model reverts to the purchase of returned products using similar sourcing processes found in the previously described in the source phase of the SCOR model (see section 3.2.1) regarding customers, retailers or scrap yards as suppliers for the reverse supply chain network. The manufacturer buys the used product, component or module in order to undergo the recovery operations already described in the previous business model. This acquisition method allows for a more control of the secondary market by the manufacturer. This was goal aimed by the buyback offer of Tesla Motors Inc. that sought the purchase of three year old cars in order to assert a stronger dominance over its products' secondary markets (Tesla Model S Buyback Offer May Generate More Revenue 2015).

This spare parts procurement method is however considered as a last resort by (Östlin et al. 2008) as a result of the higher price paid.

The reverse supply chain network pertaining this business model type is similar to the one described in the previous section. After the sale, the product is collected and undergoes recovery activities in order to, through the cannibalization of its valuable parts, produce a new product.

4.2.5 Voluntary-based and Recycling

In order to maintain a green or sustainable brand image thus profiting from higher client retention rates, many manufacturers engage in recycling operations for their reused products with some even assuming recycling costs. This green branding policy helps the manufacturer finding new market opportunities as well as gaining a competitive advantage. Other driving forces regarding the engagement in voluntary-based collection with the purpose of recycling used products are the directives put in force by the entitled organizations directing the responsibility of waste management towards the manufacturers, being the two previously mentioned directives, Council Directive 1999/31/EC and Directive 2002/96/EC of the European Parliament and of the Council (European Council 4/26/1999; European Parliament and Council 2002) two examples of such practices. Samsung, Philips and Apple are among electronic equipment manufacturers that already provide and encourage free of charge recycling services (Apple 2015; Samsung Recycling Direct; Philips - Electronics Reuse & Recycling).

In order to reduce the high collection uncertainty inherent to this collection method, increasing the control of the reverse supply chain collection operations, the OEM can revert to a free pick-up collection system thus assuming all collection planning and logistic costs. This is the case of the Lexmark Collection and Recycling Program (LCCP & LECP), offering their customers "*choices for disposal of EOL Lexmark products and supplies*" (Lexmark Equipment Collection Program (LECP)) , recovering a share of the products' remaining value upon their recycle.

Even though not directly applied to the manufacturers, another example of a voluntary based collection is the Directive 2006/66/EC (The European Parliament and Council 9/26/2006) that, driven by ecological factors, imposes the waste management of end of life batteries being the collection entities forced to provide "accessible collection points" in order to "take back waste portable batteries or accumulators at no charge to the end user". All collected products will then "*undergo treatment and recycling"* complying with "*health, safety and waste management*" regulations. (The European Parliament and Council 9/26/2006, pp. 6–7).

The recovery of the returned products is made through the recycling processes already described in the first business model (Leasing and recycling). In short, the product is received, in all examples provided through a bring-system, dismantled and inspected in the sorting phase of the reverse supply chain, and redirected to the recycling phase where the unrecyclable parts are disposed and the valuable scrap recovered and either sold or reintegrated in the source phase of the forward supply chain.

4.2.6 Credit-based and Reuse

Regarding the relation established between the customer and the manufacturer, this business model type is very similar to the third business model described (refer to 4.2.3). The difference resides in the fact that instead of receiving the previously paid deposit fee upon the return of the used product, the customer receives vouchers, promotion promises or in alternative points within a credit system according to the condition of the returned product, that allow for discounts in future purchases

The benefits of such policy are very straightforward. The manufacturer gains some level of control over the recovered products or spare parts flows simultaneously binding the costumer for a future sale while the customer still profits from reduced prices. This policy however does not share the same 1:1 ratio described in the deposit-based transactions as the customers are able to and encouraged to return as many used products as they wish.

An example pertaining this business model type is Apple's reuse and recycling program, according to which the manufacturer accepts shipped used products from end-users restoring the value of the returned product if the product qualifies for reuse or in the case of products deemed to have no residual value, assuming the product recycling costs (Apple 2015).

4.3 Key Performance Indicators (KPIs)

Some indicators were already mentioned in the previous chapter in order to justify the importance of inclusion of such factors as the number of contracts and recycling revenues (see chapters 4.1 and 4.2 respectively). The notions of life-cycle overarching costs and revenues refer to the total revenues and costs attributed to the operation of a reverse supply chain. The **net profit** is then the difference between these two KPI, allowing the manufacturer a quick and simple assessment of the profitability of the business model in study over the time.

In the simulation model developed, the capital investments necessary to contemplate the fixed costs like the capital employed to lease or acquire facilities needed for the operation of the manufacturer are contemplated in the capital invested variable. The possibility to use this input opens the ground for an analysis of such investments in the overall performance of the organization. As such, in order to evaluate the returns resulting from the manufacturer investments, the **return on capital employed (ROCE)** expresses the ratio between the profit generated in an accounting period before taxes and/or interests (EBIT), and the capital invested in such period (Law 2009), being the capital invested, pre- and after tax, calculated as follows (Damodaran 2006):

$$Return\ on\ Capital_{PRETAX} = \frac{Earnings\ Before\ Interest\ and\ Taxes}{Average\ Book\ Value\ of\ Capital\ Invested\ in\ Project}\text{, and}$$

$$Return\ on\ Capital_{AFTERTAX} = \frac{Earnings\ Before\ Interest\ and\ Taxes\ (1-i)}{Average\ Book\ Value\ of\ Capital\ Invested\ in\ Project},$$

where i is the corresponding tax rate.

4.4 Conclusion

In this chapter the business model types that are object of study in the course of this work were differentiated as follows:

BM1 – Leasing and recycling: The customer leases the product for an agreed term and fee, after which a decision regarding a contract extension has to be made. If the customer decides to extend the leasing period, another term is applied; otherwise the product is collected and undergoes recycling operations in order to recover part of the remaining value.

BM2- Renting and reuse: The customer leases a product for a short period of time, after which the decision whether to re-rent the product or return it is made. After the collection, the product undergoes testing and refurbishing operations so that it can be re-rented.

BM3- Deposit-based and remanufacturing: The product is bought for a lower price in exchange for a caution deposited in the moment of purchase which is refunded when the product is returned. After this collection, the product is examined with the purpose of separating the working and reusable components from the non-functional or obsolete ones in order to reintroduce the firsts into the production phase of the forward supply chain.

BM4- Buy-back and remanufacturing: The reused product is bought by the manufacturer from the end-user, retailer or scrap yard in order to be remanufactured. This form of acquisition is higher than the previously mentioned however it allows a very low uncertainty regarding the returns' reception.

BM5- Voluntary-based and recycling: Usually being driven by environmental or legislative issues, it contemplates the situation in which the end-user free-willingly returns the used product free of charge. When not shipped directly to the OEM, the product is collected following a pick-up system and undergoes recycling operations.

BM6- Credit-based and reuse: Similarly to the deposit-based business model, the client receives a monetary value in the moment of return in the form of voucher or credit points, susceptible to be used in the purchase of another product. This binds the customer option within the OEM product offers while providing a reduced price in next purchases. The product then undergoes refurbishment operations and is then reused.

Additionally both the parameters relevant for the evaluation of the previously described reverse supply chain business models were identified, explained and analysed, with special incidence to the **products' residual value, operational costs, number of contracts, price of raw materials, willingness to pay** and **usage intensity**. The performance measure of the reverse supply chain business modules performance is made through the analysis of the relationship between the **lifecycle overarching revenues** and **costs** and with the help of the investment decision **rule return on capital employed**

5 Simulation Model

This chapter is focused on the explanation of how and to what end system dynamics models operate as well as on the establishment of the simulation's assumptions and the entire presentation, explanation and validation of the simulation model used to assess the evaluation of reverse supply chain business models.

5.1 System Dynamics approach

A computer-aided simulation approach suitable for the design and understanding the evolution of complex systems (Forrester op. 1961) focuses on the analysis of the interaction between physical processes, information flows and managerial polices aiming to model the dynamics affecting the study variables (Vlachos et al. 2007) and simulate the conditions under which the study system can evolve. This model approaches the problem in a holistic way, focusing on the relations between all the elements of the study rather than on the elements in question.

The model is built upon the representations of feedback mechanisms in causal loops that identify the relationships between two types of variables: **rates** or flows, like remanufacturing, collection or selling rates, and **the states** also called stocks or levels which integrated over time according to flow variations consist on accumulations in the structure, i.e. inventories or the accumulative profits in any given time. This flow model is then characterized by the continuous variation of its states being therefore categorized as a continuous simulation approach, as opposed to some discrete simulation methods described in section 3.3.2. This variation is obtained through the quantification of the relevant facts and the design of the structural relationships throughout a given time frame.

After the application of an initial disturbance in the system, two types of feedback mechanisms can be identified. In the **reinforcing loops** or **positive feedback loops** this initial disturbance will lead to further change of the associated variables. In the case of the **negative** or **balancing feedback loops**, this initial disturbance leads to an equilibrium situation.

A causal loop proposed by Lehr et al. for the analysis of the material flow of remanufacturing and collection activities is presented in figure 5.1Figure 5.1 in order to provide a basic explanation of a causal loop diagram (Lehr et al. 2013).

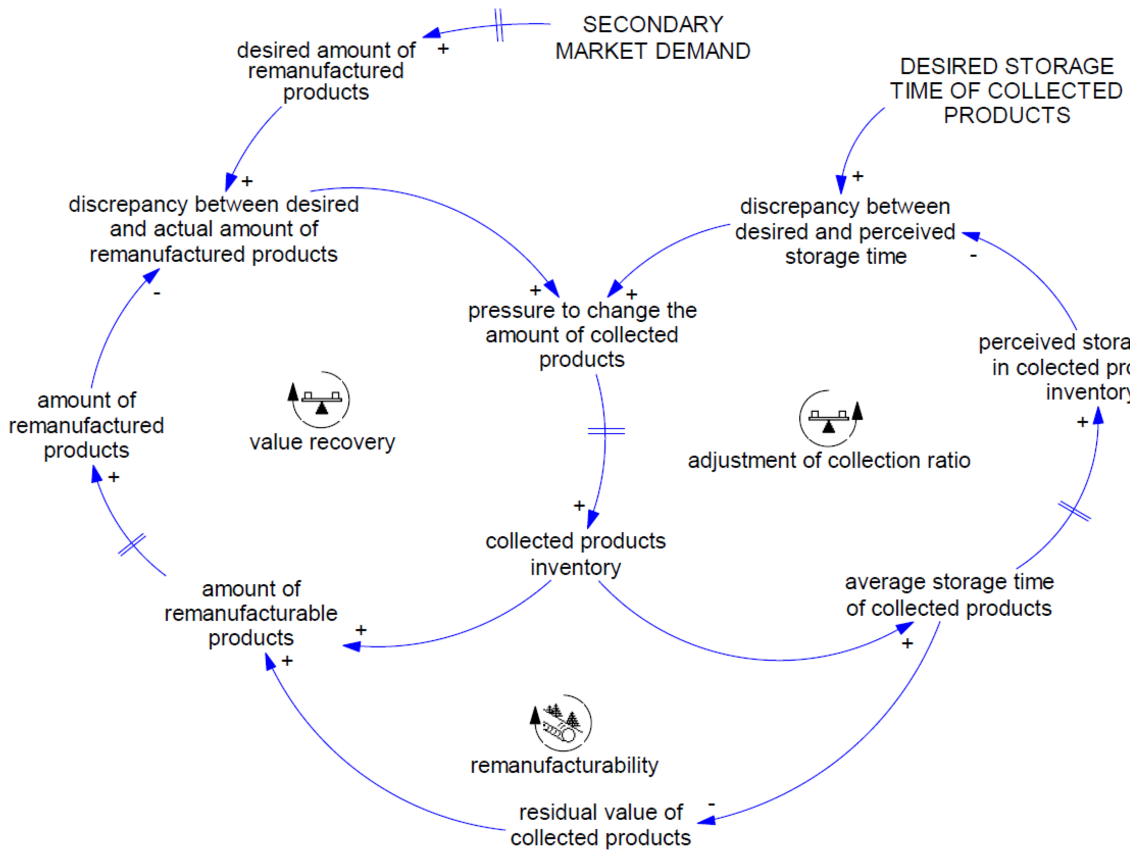


Figure 5.1 – Lehr et al.. "Causal loop diagram for collection and remanufacturing activities". *From waste to value – a system dynamics model for strategic decision-making in closed-loop supply chains.* p12

Focusing on the value recovery loop it is seen that an increase of the value of the secondary market demand will lead to a sequential increase of the value of the pressure to change the amount of collected products which in turn will increase the amount of remanufacturable and remanufactured products eventually leading to a smaller difference between desired and actual amount of remanufactured products. If all inputs of this particular loop would be assigned a null value, the variable **discrepancy between desired and actual amount of remanufactured products** would have an end value of zero which means that this is a balancing or negative feedback loop.

Another notation in the causal loops worth mentioning is the two transversal lines representing a delay effect between two variables which can be seen, among others, between the **secondary market demand** and the **desired amount of remanufactured products** variables.

In this loop are also present two external variables (**secondary market demand** and **desired storage time of collected products)**, which serve as inputs to the system and therefore are not object of analysis since the simulator knows their values in any given time.

Depending on the number of variables considered or inherent to the problem in case, an increase of the sophistication and range of the causal loop diagram in which it is based, allows the system dynamics based approach to be an useful tool to predict the evolution of a complex and dynamic system that can be easily corrected or revised to model additional questions different than the research questions posed in the beginning of the study. However this method is only capable of running a version of a problem at a time, and can become overwhelmingly complex as different variables with distinct interrelations are brought into consideration.

5.2 VENSIM model Development

Developed by Ventana Systems, Inc., VENSIM is a software suitable for the simulation and analysis of dynamic systems, its uses including the development, analysis and packaging of dynamic feedback models (Ventana Systems Inc.). A useful feature of this software, in addition to the possibility to easily design and create models, is the ability of comparing multiple simulation runs and changing the variables of a single run allowing for an interactive quick analysis of the model. VENSIM's interface grants the user the ability to vary the input of certain variable types through the means of slide bars, updating the outputs in real time. In this model this feature is used to alter certain values to the user's (in our case the manufacturer) convenience, allowing a great level of interactivity and control over the model's behaviour. An example of this feature is presented on figure 5.2, where the values assumed by each variable are represented by the corresponding graphics over the variable name and the model controlling input bars are under the constants' names

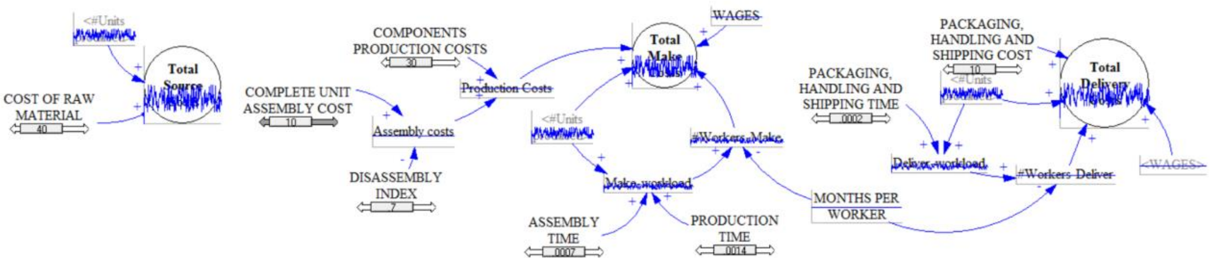


Figure 5.2 - Cost structure of the forward supply chain

The VENSIM model was created in a three phase process. In the first place, a material flow was created providing a basis from where the different costs and revenues could be derived. This material flow is controlled by a set of triggers that, working as valves, redirect the products through the model depending on the business model in study.

The four Boolean triggers are the **authorization trigger** placed directly after the stock variable **collected products** and the **reuse, remanufacture** and **recycle triggers**, all immediately after the stock of **products accepted for recovery** as depicted in figure 5.3Figure 5.3. While the last three variables redirect the material flow according to their respective business model, by directly controlling their respective rate, the first one's use is to control the whole engagement in recovery activities. In the case where the authorization rate is zero, no recovery is pursued, being all collected products disposed.

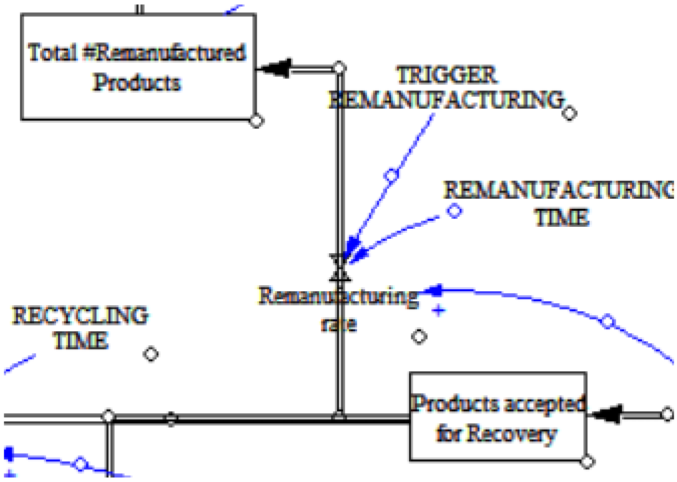


Figure 5.3 - Example of a material flow controlling trigger

The material flow illustrated on figure 5.4Figure 5.4 is above all controlled by the **monthly demand** which regulates the number of orders and ultimately the number of products produced and reintegrated in a given month. This monthly demand depends in turn on the **willingness to pay** variable and on a set of triggers that choose which curve will be used (see section 5.2.1). After this point, the **number of orders accumulated** is compared with the number of units that can be reintegrated (the **remanufactured** and **reused products**). The difference between these two values is the number of units produced in a given month, which added to the simultaneously reintegrated products constitutes the input for the **number of products** in use level. In this point, for the business models referring to leasing contracts (BM1 and BM2), a decision is made to whether or not extend the contract, after the term is expired. This factor is controlled by the **contract extension rate**, which defines, based on the number of initial contracts and on the **usage duration**, how many will be extended for a second term. The **collection rate** is also influenced by this usage duration factor that simulates the time a product remains in use (see section 5.2.2). After collection, the products are either disposed or set for recovery depending on the value of the authorization trigger, after which as previously said, undergo the recovery operations accordingly to the business model in study. The reintegration of the product follows two slightly different procedures in the cases of reuse and remanufacturing based business models. In the remanufacturing case, the product is directly reintegrated in the forward supply chain, FSC, if there are orders pending (the cost structure defines the costs involved with the remanufacturing processes, taking there into consideration the loss of value suffered by the product). In a reuse-based case, a **reused product demand** is defined based on the willingness to pay for a reused product and the product re-sold or re-leased.

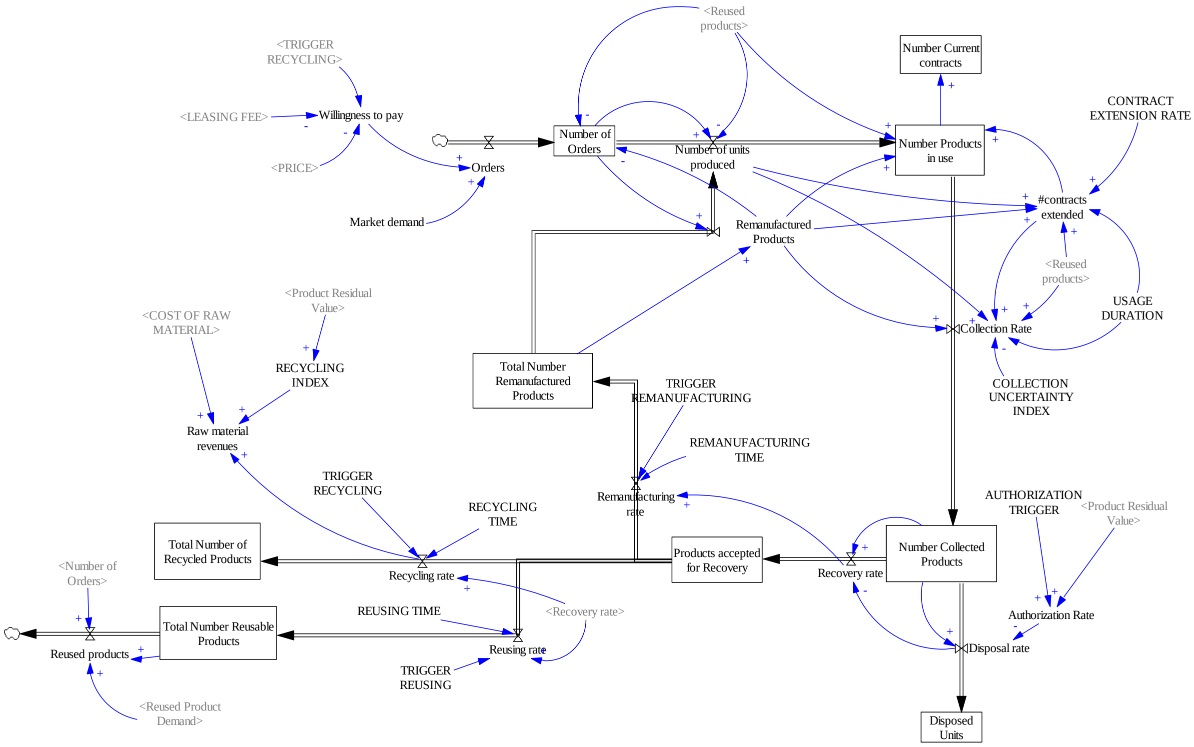


Figure 5.4 - Material flow sub-model

The costs deriving from the material flow establish the cost structure of the model developed and define one of the two inputs of one KPI, the lifecycle overlapping costs of the entire chain. These costs are obtained through the accumulated average costs per unit. The sequence of operations considered and respective costs related to the FSC (see figure 5.2) emulates the SCOR model framework, already analysed in chapter 3.2.1 and as it was not the focus of this work was only superficially developed. It consists on the main activities concerning each FSC phase, namely **sourcing costs** based on the **raw material price**, production costs (**make costs**) based on the **assembly** and **production costs** and **prices** and **delivery costs**, based on **packaging, handling and shipping costs.** These costs however refer to an average cost per unit and, as no considerations were made pertaining economies of scale in the make of this model, the total costs assume a linear correlation between the average costs described and the number of units produced. Still related to this sub model, the **disassembly index** represents the complexity of a product's assembly. This constant was introduced so that the influence of a product's assembly or disassembly level could be felt in the costs of its production, in this case the make costs, in the costs of the sorting phase where the product is disassembled for inspection and in the remanufacturing phase, more specifically, in the reassembly of the product.

The costs concerning the reverse supply chain phases were derived from an adaptation of the SCOR model by (Novoszel 2012) in which the previous forward supply chain focused framework is slightly adjusted to contemplate a reverse supply chain case, illustrated in figure 5.5. The complete execution structure of the adapted model is presented on Annex A: SCOR model adaptation's process structure (according to NOVOSZEL, 2012).

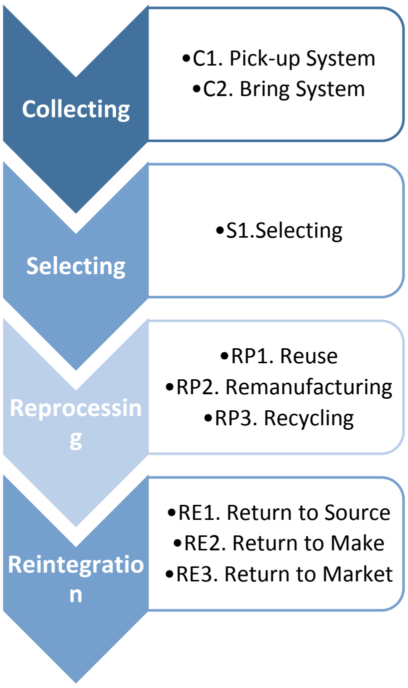


Figure 5.5 - SCOR Framework for Reverse Supply Chains (according to (Novoszel 2012)

As such, occurring in the most upstream point of the reverse supply chain, the collection and sorting costs, common to every business model, are presented in figure 5.6.

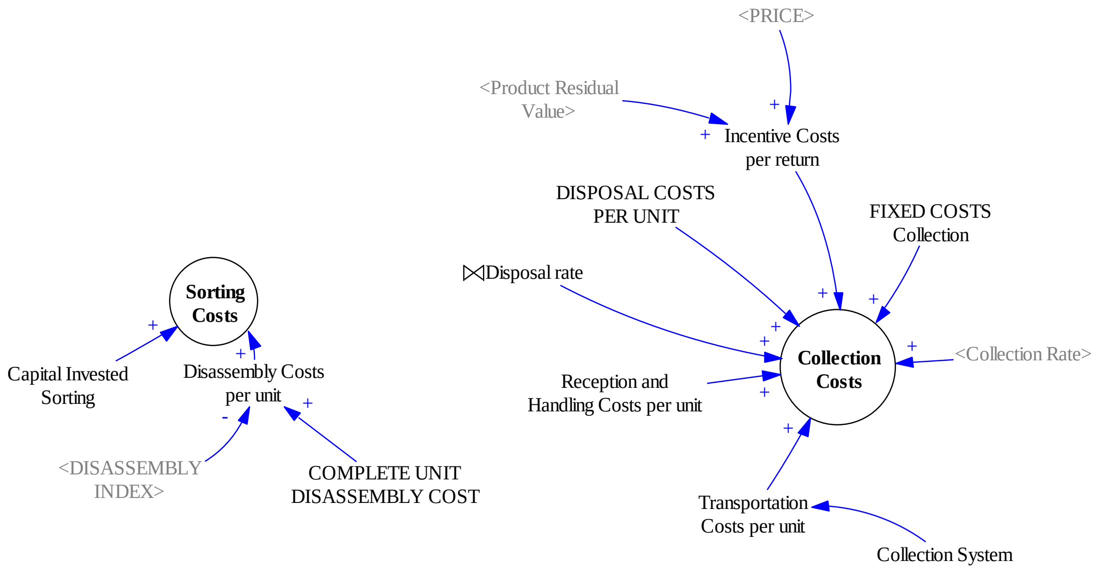


Figure 5.6 - Sorting and Collection Costs sub-models

The collection costs resume every cost associated not only with the collection of the returned products but also the ones concerning the capital invested on the **incentives to return**. These incentives can be the deposit (pre-established value), the credit (dependent on the residual value) or the buyback option (determined by the price) from the business models 3, 4 and 6 respectively.

The **collection system** variable defines which collection system is used in the business model. While its value is at zero, it represents the bring system, setting the value of the **transportation costs per unit** to zero. When at 1, the transportation costs assume its own value as determined by the pick-up system.

Concerning the **sorting costs**, they are, as previously mentioned, determined by the disassembly index.

Further downstream lie the reuse, recycling and remanufacturing costs, presented in the figures 5.7 and 5.8

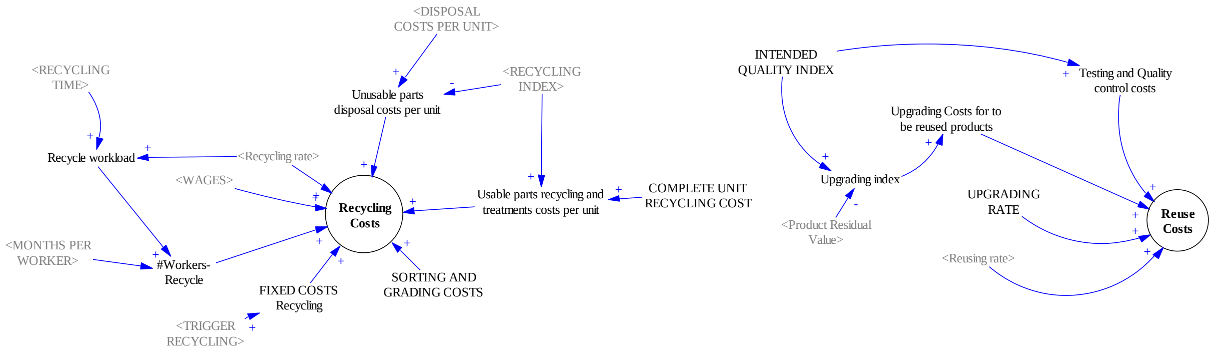


Figure 5.7 - Reuse and Recycling Costs' sub-models

Both reuse and remanufacturing models depend on a variable named **intended quality index**, which together with the product residual value controls the upgrading and remanufacturing level index respectively which represents the deepness level of such activities.

The **re-assembly costs** are as already mentioned function of the disassembly index.

Regarding the recycling costs, the recycling index contemplates the value possible to be recovered from one used product as a percentage of its residual value. This is meant to allow a setting in which not all the product’s value can be recovered.

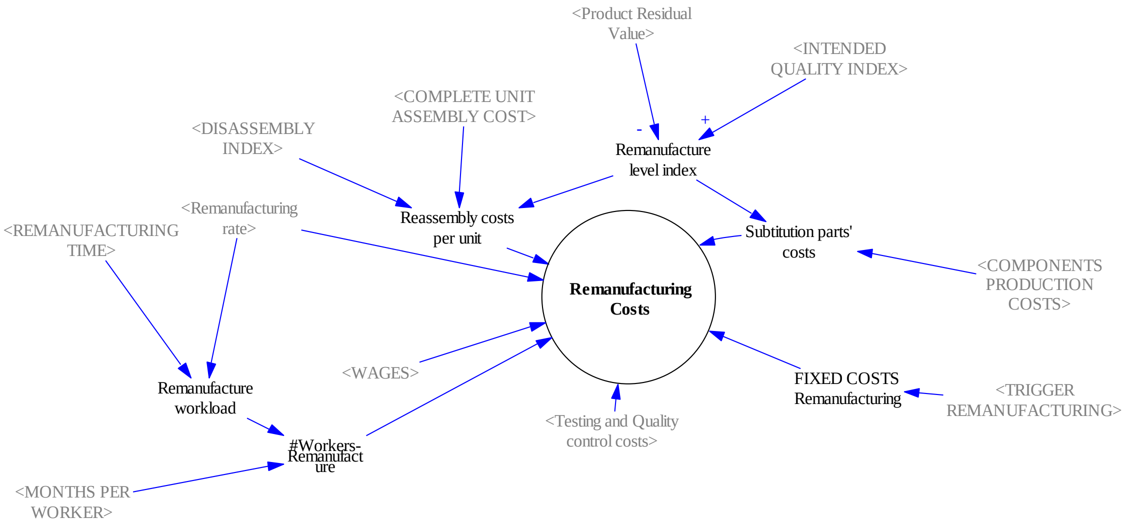


Figure 5.8 - Remanufacturing Costs' sub-model

The final development phase is focused on the establishment of the revenue sources relevant for every business model which after providing us with the lifecycle overlapping revenues allows the analysis of the profits recurring from the operational activities of the company.

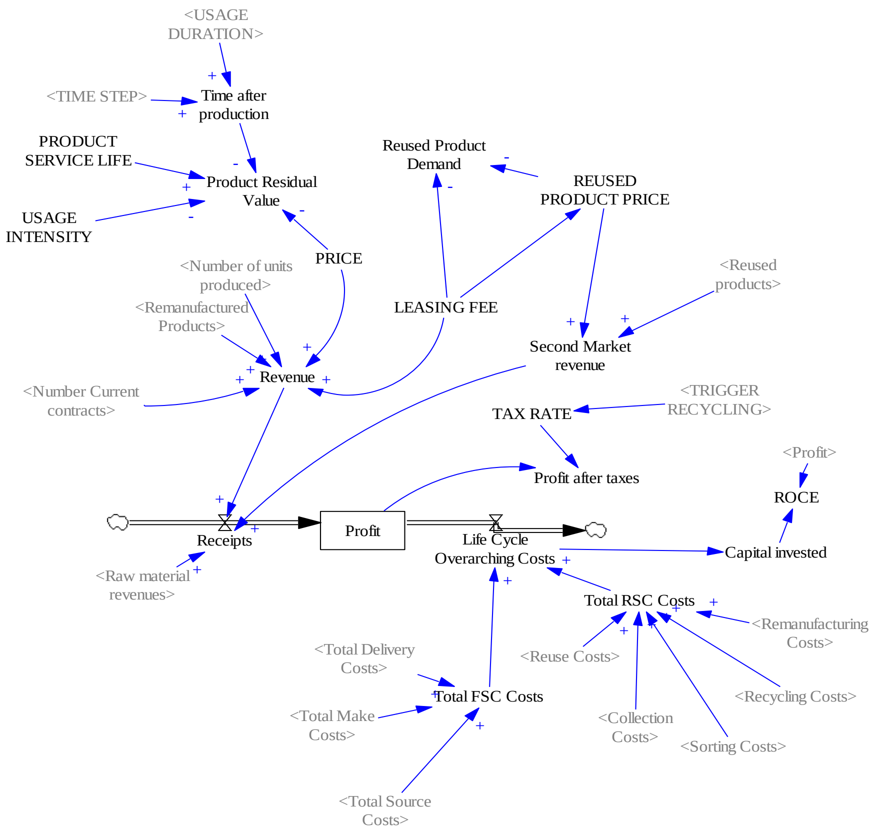


Figure 5.9 - Revenue's sub-model

It is in this sub-model where the product residual value is calculated, depending on the **usage duration, intensity**, the **product service life**, and the **product's original price.** The overarching costs consisting on the aggregate costs pertaining to each supply chain phase. On the other hand, the revenues are calculated pondering the leasing fee (the renting fee is here understood as a short duration leasing fee) with the contract duration and number of contracts. On the other hand of the revenues, the sales profit is determined through the number of units produced or reintegrated (in the business models 3,4,5 and 6 the leasing fee is set to zero) and their price.

The profit before tax is the difference between the total amount of receipts and costs.

Concerning the tax rate, its goal is to allow a simulation in which a certain business model profits from reduced taxes when, for example, engaging on recycling activities.

5.2.1 Model constants and converters

In this section only the more relevant constants pertaining the different business models differentiation and special situations in the whole model will be presented. To provide a deeper and complete understanding of the model developed the constants and converters not specified in this section are provided on annex C: model constants and variables

A constant possibly subject of alteration according to the convenience of the supply chain manager, in order to better evaluate the performance of the supply chain is the **product remaining value**, which when removed from the effects of the material flow, allows an assessment of the best business model for an individual product.

The **operations time** alike their unitary costs are, in the test runs performed, mere reference values, to allow a comparison between the alternatives studied. Thus, the main focus when setting up the simulations runs was to guaranty that it was at all times worth it in the long run to perform recovery activities, assuming, for example, that the time needed to remanufacture a product was at all times smaller than the time needed to produce one,

Also the **wages** were considered, calculated using the minimum wage in Germany as the reference wage (8.5€/h). These are used to determine how many workers each phase of the supply chain needs and their respective costs.

The **contract extension rate** depends from business model to business model. It was considered to be at the highest level for the BM2 (0.8), meaning that 80% of the products rented will incur in a second renting term, 0.2 for the BM1 and zero for the remaining four.

Also the **usage duration** varies from business model to business model. On the business models that contemplate a sale, it was considered that the average duration until return was equal to 3 year (36 months). The case is completely different when considering the remaining two business models. In the case of the leasing contract, it is valid for 18 months, while the renting contract for 3.

The **fixed costs** simulate the costs associated with the leasing of the facilities or equipment required to maintain the operation. It was considered that an initial larger amount was paid before a yearly rent.

5.2.2 Model Equations

In this chapter only a few important equations will be presented. For the complete review of the interactions between each variable developed in the model, the equations not explained in this section are released on annex C: Model constants and variables.

The **willingness to pay** factor determines the ratio between the total and the effective demand for the product. As such, following an example provided by Breidert, the willingness to pay functions are defined by the Gaussian or “bell” curve’s general equation:

$$wp = ae^{-\frac{(Price-b)^2}{2c^2}},$$ (Breidert 2006, p. 99)

Because the curves always peak for the value one, meaning a 100% compliance of the total demand, *a* remains constant through the study of the model’s behaviour. As such, the only coefficients that vary according to the business model in study are *b*, reflecting the position of the aforementioned peak, and *c*, which is the width of the bell. Their values are presented on table 5.1.

Table 5.1 - Willingness to pay coefficients for the different business models

	a	*b*	*c*
BM1	1	0	8
BM2	1	0	6
BM3,BM4	1	10	130
BM5	1	10	140
BM6	1	10	100

The intent with the implementation of the curves presented on figure 5.10 is to simulate the difference between customers' perceptions regarding different products. These curves associate the price of different product types with the percentage of original customers willing to acquire them. To take into consideration the fact that the consumer expects to pay a premium price for a green product (Mansvelt 2011, p. 256), the willingness to pay for recycled products was set the highest to take into consideration the effect of these product's green image has on customers.

As such, as an example, for an asking price of 100€, only 81% of the total number of potential customers would accept paying such price for a recycled product (BM5) , 79% for an original product (BM4 and BM3) and 67% in the case of a reused product (BM6).

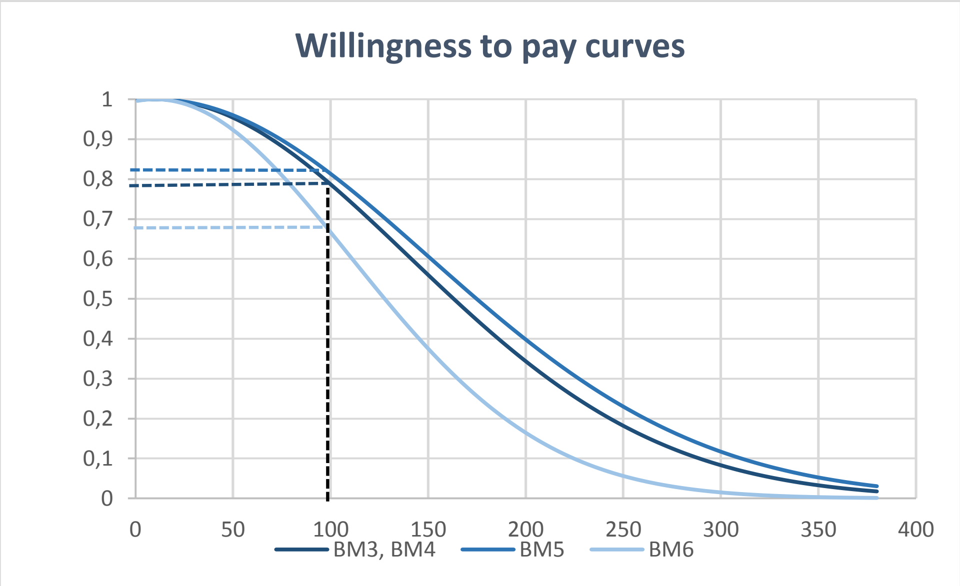


Figure 5.10 - Willingness to pay functions pertaining sales-based business models

Regarding the business models related to leasing fees (BM1 and BM2), the willingness to pay curves assumes the form depicted in figure 5.11.

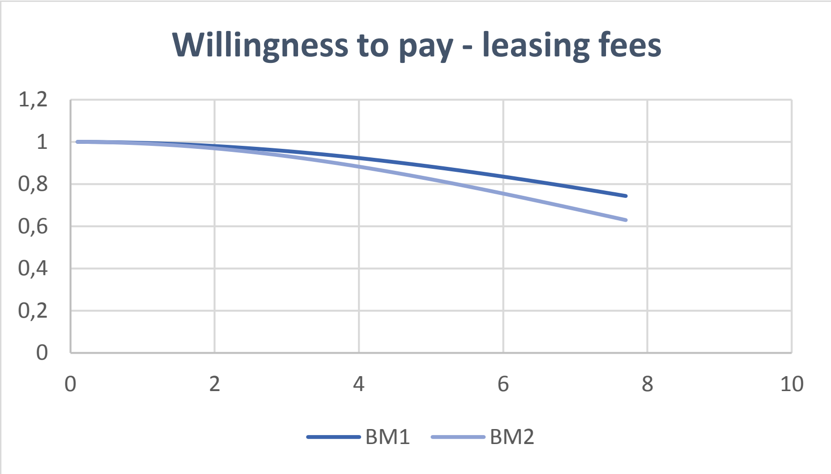


Figure 5.11 - Willingness to pay functions pertaining leasing-based business models

As previously mentioned the **Monthly demand** is a function of the willingness to pay. The total original market demand is given by the expression:

Total Market Demand= RANDOM UNIFORM (200,700,1). This expression returns the number of orders needed to satisfy the market's demand in which any number between the minimum (200) and maximum values (700) is equally likely to occur.

However, after pondering the willingness to pay, the monthly demand or number of orders becomes:

Orders=INTEGER (Market demand*Willingness to pay). This function rounds the result of the multiplication between both variables into the lowest integer.

Concerning the rates that direct the material flow, namely the collecting rate, the remanufacturing rate, the reusing rate and the recycling rate, they have to be offset by a delay time concerning their respective operations simulating either the time regarding the operations themselves or simply, in the case of the collection rate, the delay between the moment a unit is produced and the moment when it is re-turned. This delay is implemented in the model through the use of the DELAY FIXED function under the form **DELAY FIXED (input, time, initial value).**

As such given for example the case of the collection rate, the function that describes this variable is:

DELAY FIXED (Total number of units entering the market * (1- collection uncertain-ty), USAGE DURATION ,0).

All other non-explained variable relationships, completing the model are given in an-nex C: model constants and variables.

5.1 Model Validation

In order to validate the model constructed, an analysis was made to evaluate the reaction of the material flow when under different business models influences. This is more easily done if the number of orders is given by a periodic function. This way, it is possible to easily track the material flow through the model's variable sequence.

As such, considering a periodic order of a fixed sized batch, a simulation run was performed for the two different business model groups, consisting of the ones which consider the reintegration of the product, that is the business models that contemplate remanufacturing and reusing options and the ones which such reintegration is not considered being the product recycled or disposed

For this simulation run, the time period considered was 10 years, or 120 months.

As such, setting the variables: usage duration for 12 months, the number of orders being defined by periodic pulses of 100 units each time, happening once in every 12 months and with the last pulse in the 96th month, that is two years before the time period considered elapses, and the collection uncertainty index for 0.05, that is 5% of the units sold are not recovered, the number of units produced, number of units collected and number of units remanufactured vary in the manner illustrated in the figure 5.12.

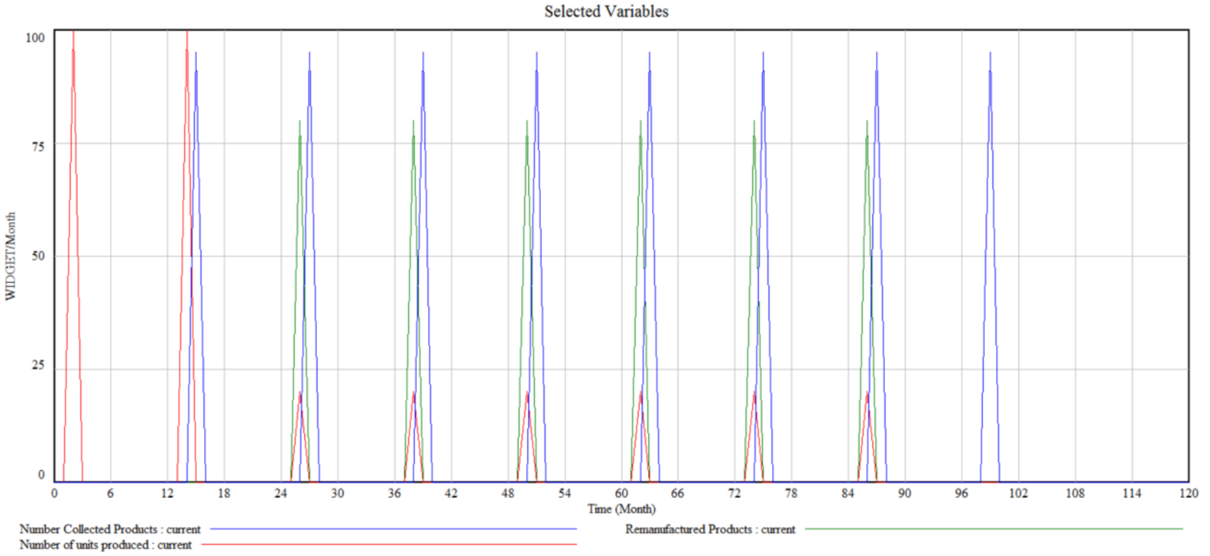


Figure 5.12 – Relationship between the numbers of units produced, of remanufactured products and of collected products.

As a consequence of both the number of orders and both the collection uncertainty and rate, the number of products still in use in the end of time period is 40, or 5% of the total number of orders received. This means that in order to answer to all orders each period considered, the number of units lost in the market has to be substituted by new ones. However, due to the short usage duration and the fact that the case considered corresponds to a remanufacturing business model, the number of products remanufactured each period remains the same as the product remaining value doesn’t suffer a relevant decrease and is returns to one once the product is remanufactures. If the case analysed concerned a reuse situation, the number of products produced would tend to increase due to the disposal of old products after collection.

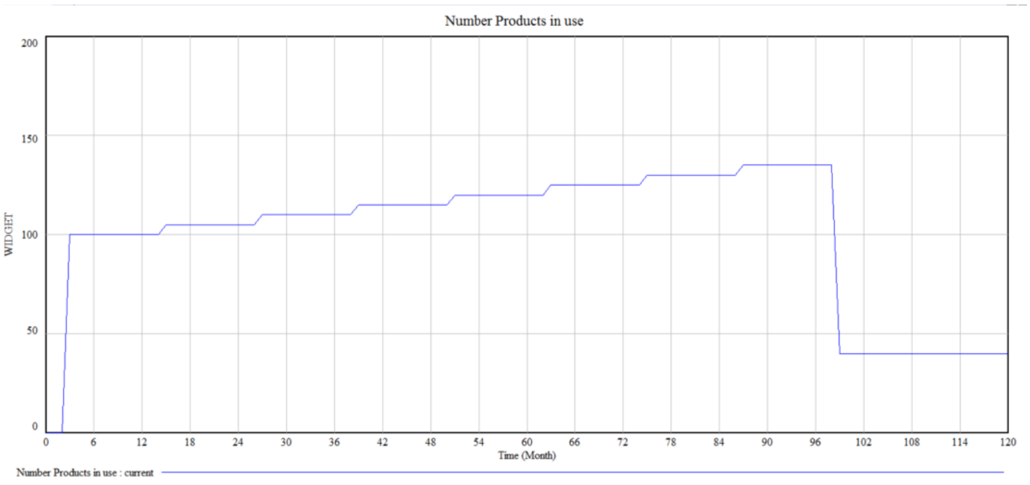


Figure 5.13 – Number of units in the market pertaining a usage duration coincident with the batch order periodicity.

The small increments seen in the **number of products in use** curve are related to the simultaneous input and output of products from the market. This happens because the usage duration and the orders periodicity coincide. By changing the **usage duration** to 18 months for example, the corresponding curve would be the one presented on figure 5.14, where because an order is received before the collection takes place, the number of products in the market increases before the first batch is taken of the market.

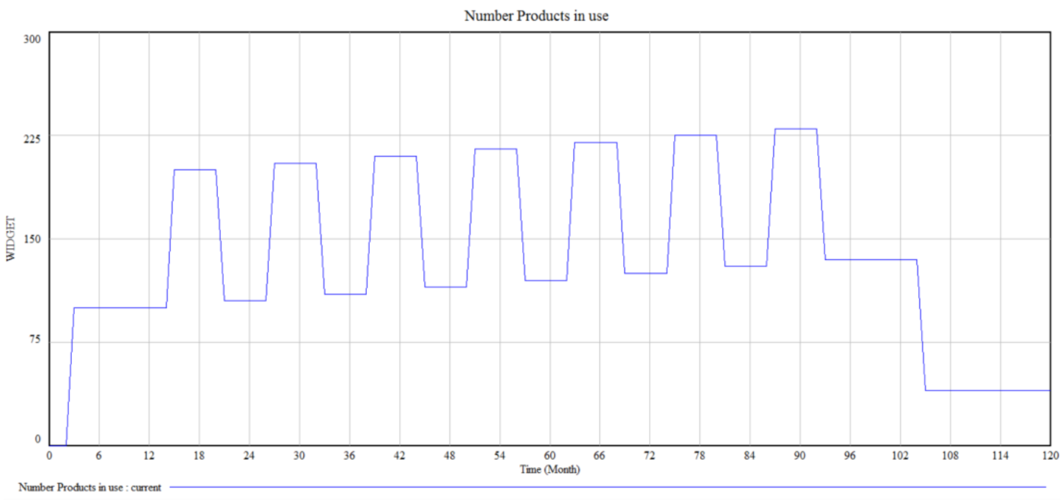


Figure 5.14 - Number of units in the market with an offset between the usage duration and the orders' periodicity.

In the business models that don't contemplate the products' reintegration, the curve, illustrated in figure 5.15, represents a more elemental situation, where the number of units produced, collected and recycled remains the same in each production's periods.

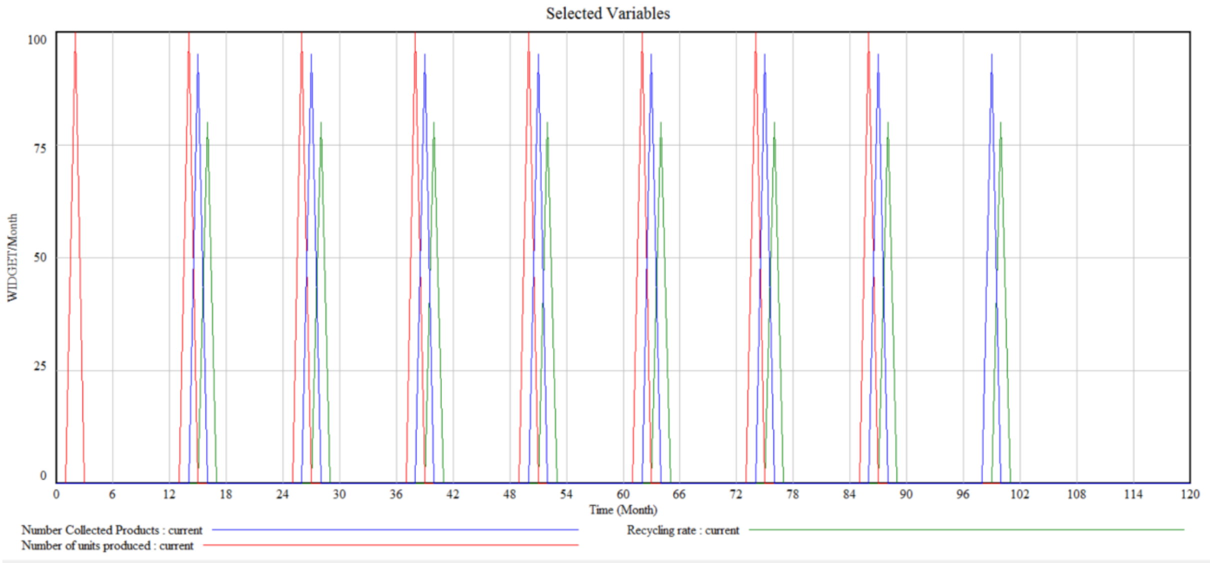


Figure 5.15 - Relationship between the numbers of units produced, of recycled products and of collected products.

With these results, it is possible to analyse the **total make costs** concerning to both situations. As it is depicted in figure 5.16, the number of reintegrated units in the forward supply chain has, as expected, a significant influence over the costs of producing new ones.

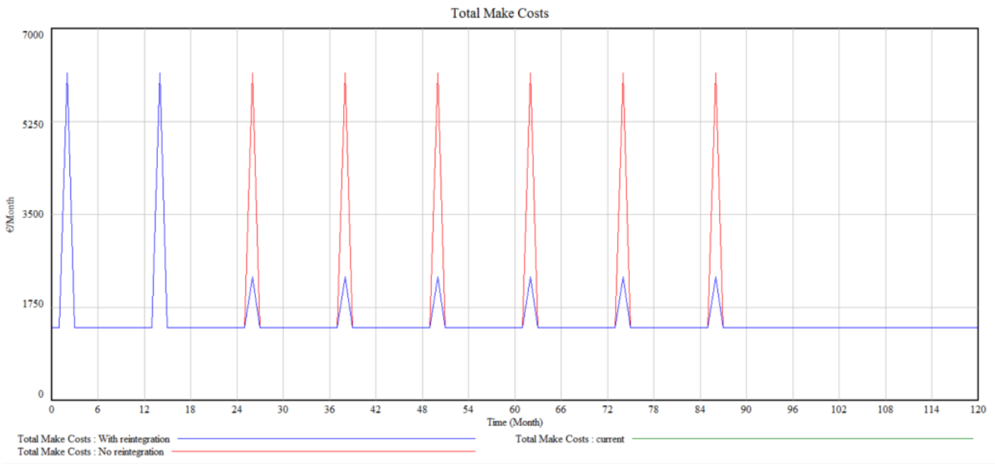


Figure 5.16 - Total make costs' difference between business models with and without product reintegration

After the material flow validation, to validate the revenues and cost structure of the reverse supply chain business models, it was necessary to define the unitary prices and costs concerning the different phases of the supply chain. To that end a run was made without engaging the RSC activities to iteratively equilibrate the operational profit setting up the critical price and costs.

The forward supply chain costs and prices were determined so that the profit would be given by the curve presented in figure 5.17.

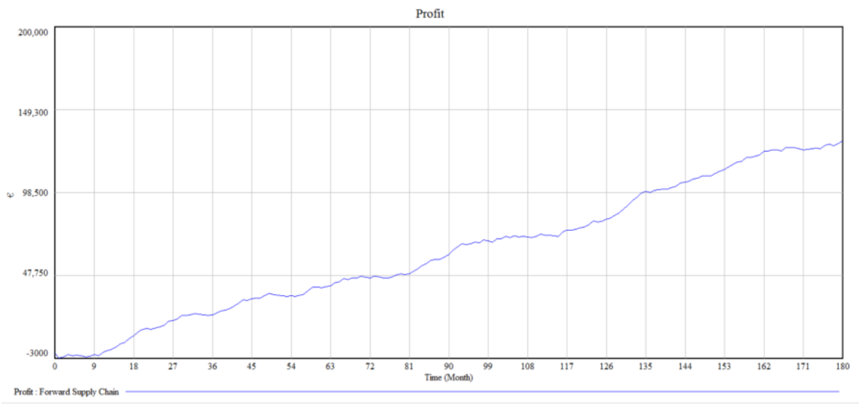


Figure 5.17 - Profit Curve

For this profit curve the costs considered were:

Table 5.2 - Base costs and price for the evaluation model

Price	Raw Materials Cost	Assembly Costs	Production costs	Shipping costs
120	40	10	45	10

With the marginal profit over the 180 months of study, presented on the figure 5.17, and with the basic costs established, presented on the table 5.3, the evaluation of the diverse supply chain business models can ensue following the considerations already mentioned in the last chapter. Thus, in order to evaluate the different business models proposed in chapter 4.2, the following values were considered for the influential parameters.

Table 5.3 - - Constant values concerning the validation run

	Price/Leasing Fee	*Usage duration*	*Contract extension rate*	*collection uncertainty*	*Incentive to return*
FSC	120	60	-	0	0
BM1	11	18	20%	0%	0
BM2	10	3	80%	5%	0
BM3	120	60	-	5%	15
BM4	120	60	-	0%	6
BM5	140	60	-	30%	0
BM6	120	60	-	0%	4,8

Based on a quick analysis of the curves obtained (see figures 5.18 and 5.19), we can in fact observe that the influence of the reverse supply chain is mostly felt on the latter half of the time interval. This is above all the effect of the delay related to the usage duration and a noticeable bigger investment in both production and in the initial fixed costs. When comparing between both leasing-based business models, the conclusion made is that a reusing-based scenario tends to be more unstable than a business model based on leasing contracts. A reason for this is the higher contract extension rate and therefore also significantly higher number of contract still valid in any given time, which increases the costs but also the profits in the long run.

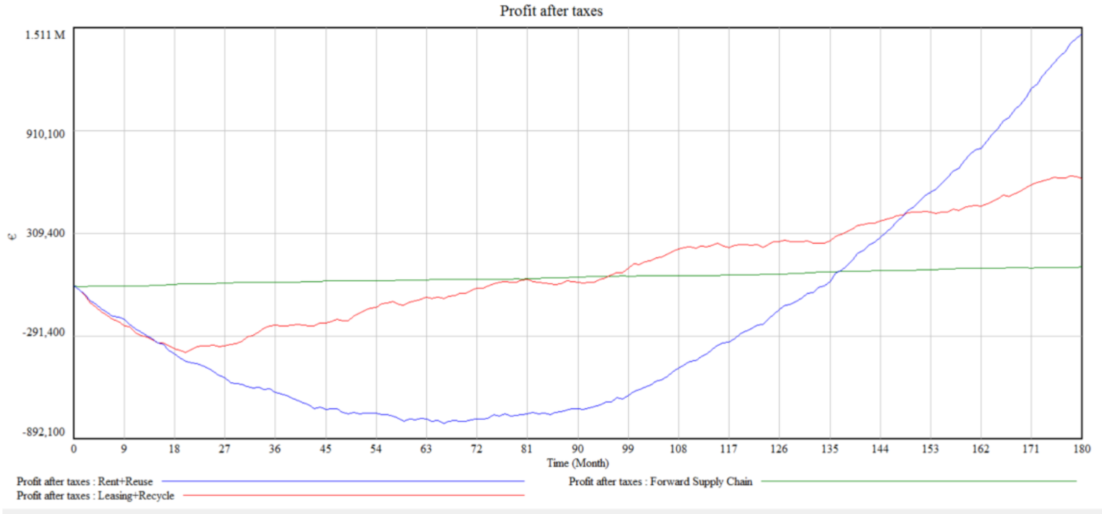


Figure 5.18 – Forward supply chain profit compared to BM1 and BM2

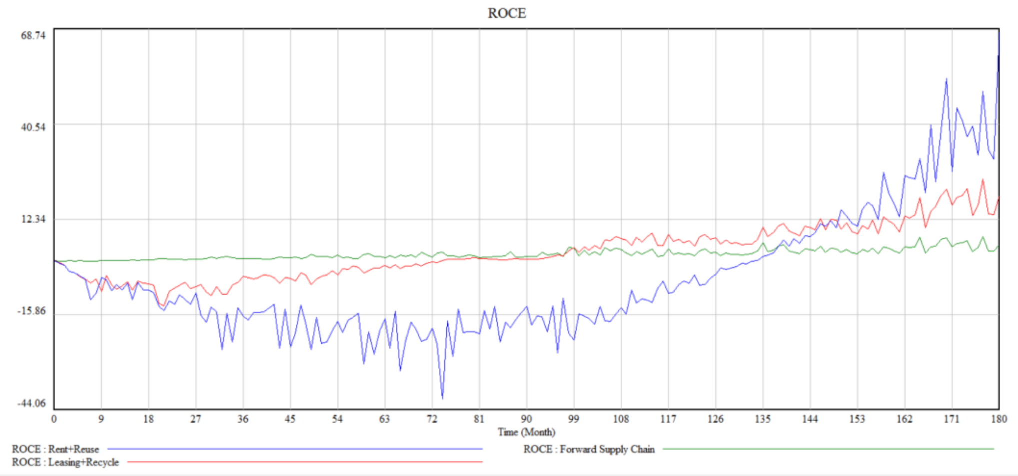


Figure 5.19 - ROCE curves of the forward supply chain and two lease-based business models

Concerning the sales-based business models (figures 5.20 and 5.21Figure 5.20), the same analysis can be done. The higher profit from can be explained through the relatively low incentive to return inherent to the business model 4, when compared to the associated non-existent collection uncertainty.

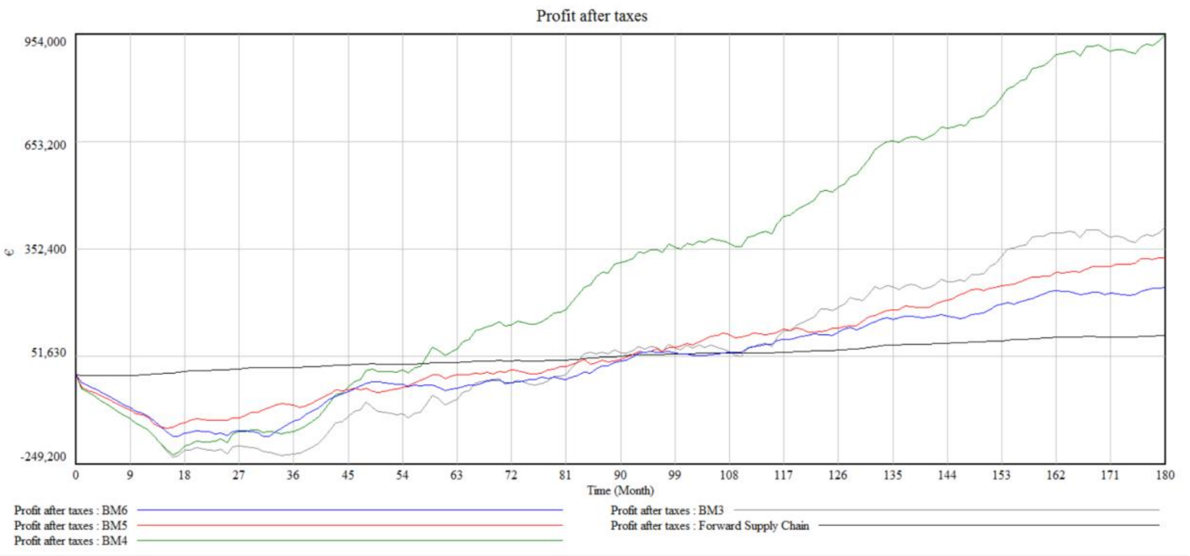


Figure 5.20 - Forward supply chain profit compared with the sale-based business models (BM3, BM4, BM5 and BM6)

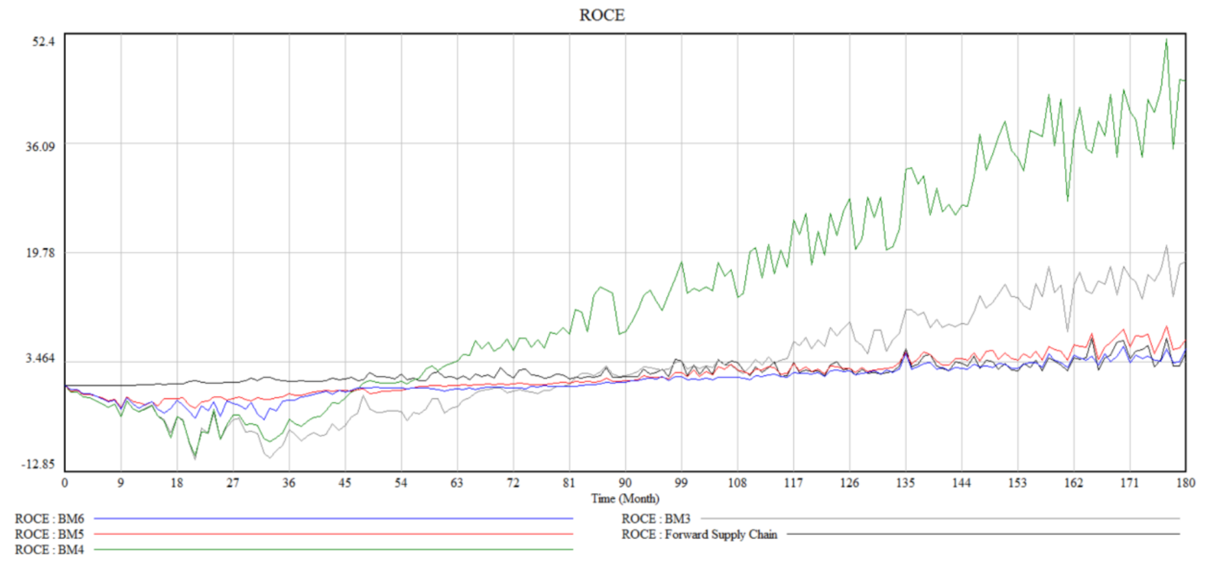


Figure 5.21 - Forward supply chain ROCE compared with the sale-based business models (BM3, BM4, BM5 and BM6)

In this final chapter the methodology behind the evaluation model developed was disclosed as well as the considerations taken in order to attest its validity. The logic behind some particular cases regarding relationships between variables of special importance was also explained in order to facilitate a general comprehension of the model in its entirety.

For the variables not mentioned or explained throughout this chapter, refer to annex C: model constants and variables.

6 Conclusions and Future Work Prospects.

This work consisted on the development of a VENSIM evaluation model based on the system dynamics approach to address the analysis of a supply chain's performance focusing on six proposed business models for reverse supply chains. It aimed to simulate, in the perspective of the manufacturer, the consequences emanating from a decision pertaining the business model chosen, thus helping in the making of such decision.

Consequently, before initiating the evaluation model design there was the need to present the current knowledge and approaches regarding the concepts reverse supply chain, business models and research methods, namely the simulation based approach of supply chain evaluation.

As such, it was understood as reverse supply chain, the sequence of activities required to retrieve a used product from the end-user to the OEM in order to either dispose the product or recover it either seeking an economic benefit from its recovery or complying with established legislation. These sequence consists on the steps: collection, sorting, recovery and reintegration, being the recovery phase further divided between the recycling, remanufacturing or reusing phases based on the decision previously made.

Regarding the business models definition, their representation was distributed into four dimensions, the consumer, the product and the financial dimensions as well as their correspondent value stream.

The consumer dimension explains how much a consumer is willing to pay for a product and the amount he is willing to buy. These factors influence directly the material flow which in turn has a great impact on the previously mention revenue and costs' flows.

The product dimension describes the kind of product retrieved as well as their value when retrieved, defining how much value can still be recovered from this particular unit. Its presence in the final model is felt through such variables: product residual value, product service life or the product's disassembly index.

Influencing the type of product handling, the value stream explains among other factors which recovery option will be undertaken and which is the range of product recovery possibilities. These factors are implemented through trigger variables (reuse, remanufacture and recycling triggers) and remanufacturing or recycling indexes that define the value recovery possibilities' range.

Finally the financial dimension pertains the revenues' source and the cost structure of the business model itself, explaining how much profit is to be made or how much is to be lost from engaging in the reverse supply chain activities of a certain business model.

In order to understand the concepts behind a system dynamics approach, an analysis of an introduced system was made focusing on the concepts of causal loop and the influence of reinforcing and balancing loops.

It was then endeavoured to design a working system dynamics evaluation model for reverse supply chain business models which based on the material flow, the model was then designed to establish a relation of the revenue flows originated from the analysis of the business model in study and the cost structure of the reverse supply chain added to the influence of such business model in the relevant parameters.

Separating the leasing-based business models and the sales-based business models from the basic forward supply chain analysis, the model was then validated with the analysis of its response to hypothetical initial values of the parameters concerning the different business models and the material flow.

The suggestions for future research works pertaining the analysis of reverse supply chain business models, can direct to the evaluation of other business models than the ones studied, the implementation of other criteria regarding the decision making processes, a study approaching the reverse supply chain operations in particular as opposed to a more holistic analysis developed in this work in order to, defining exactly the activities and costs required, namely warehousing costs or the effects of a centralization or decentralization of the recovery activities, factors not contemplated in this work, in the performance of the supply chain.

Because all the products were, in this work considered all equals and indivisible, an interesting approach for an eventual follow-up research project would be the analysis of different products' life cycle within a closed loop supply chain a an eventual approach regarding the product's unity in the recovery phases, allowing for example part of the product to be remanufactured being simultaneously the remaining components recycled.

1 Publication bibliography

BMW Erleben : Mieten. Available online at http://www.bmw.de/de/topics/faszination-bmw/bmw-erleben/mieten.html, checked on 2/15/2015.

Lexmark Equipment Collection Program (LECP). Available online at http://www.lexmark.com/en_us/products/supplies-and-accessories/collection-and-recycling-program/lecp.html, checked on 2/16/2015.

Philips - Electronics Reuse & Recycling. Available online at http://www.usa.philips.com/about/sustainability/recycling/reuse_recycle.page, checked on 2/16/2015.

Samsung Recycling Direct. Available online at http://www.samsung.com/us/aboutsamsung/citizenship/usactivities/environmentalinitiatives/recyclingdirect/, checked on 2/16/2015.

SCOR Framework - The APICS Supply Chain Council. Available online at http://www.apics.org/sites/apics-supply-chain-council/frameworks/scor, checked on 1/4/2015.

Brockhaus-Enzyklopädie (2006). 21., völlig neu bearb. Aufl. Leipzig, Mannheim: Brockhaus.

Mercedes-Benz Rent - Mieten Sie den Mercedes Ihrer Wahl. (2015). Available online at https://mieten.mercedes-benz.de/faq/, updated on 1/21/2015, checked on 2/15/2015.

Tesla Model S Buyback Offer May Generate More Revenue (2015). Available online at http://www.bloomberg.com/news/articles/2013-09-10/tesla-s-model-s-buyback-offer-builds-in-used-car-revenue-boost, updated on 2/16/2015, checked on 2/16/2015.

Apple (2015): Apple - Recycling Program. Available online at https://www.apple.com/recycling/, updated on 2/7/2015, checked on 2/17/2015.

Becker, Habil Wolfgang (2011): Geschäftsmodelle im Mittelstand. Otto-Friedrich-Universität Bamberg, Bamberg, Germany. Deloitte.Mittelstandsinstitut an der Universität Bamberg.

Blackburn, Joseph D.; Guine V. Daniel R.; Souza, Gilvan C.; van Wassenhove, Luk N. (2004): Reverse Supply Chains for Commercial Returns. In *California Management Review* 46, checked on 10/15/2014.

Blumberg, Donald F. (2005): Introduction to Management of Reverse Logistics and Closed Loop Supply Chain Processes: CRC Press.

Breidert, Christoph (2006): Estimation of Willingness-to-Pay. Theory, Measurement, Application. Wiesbaden: Deutscher UniversitSts-Verlag; GWV Fachverlage (Gabler Edition Wissenschaft).

Cao, Qing-kui; Li, Juan: Reliability analysis and evaluation on member enterprise of manufacturing supply chain based on BP neural network, pp. 474–479.

Damodaran, Aswath (2006): Applied corporate finance. A user's manual. 2nd ed. Hoboken, NJ: John Wiley.

David J. Teece (2010): Business Models, Business Strategy and Innovation.

de Brito, Marisa P.; Dekker, Rommert (2003): A Framework for Reverse Logistics. In *ERIM Report Series Research in Management*, 2003.

Dyckhoff, H.; Lackes, Richard; Reese, J. (2004): Supply chain management and reverse logistics. Berlin, New York: Springer.

ETMra (2011): End of life tyres - A valuable resource with growing potential.

European Council (4/26/1999): Council Directive 1999/31/EC of 26 April 1999 on the landfill of waste. Directive 1999/31/EC.

European Parliament and Council (2002): Directive 2002/96/EC of the European Parliament and of the Council of 27 January 2003 on waste electrical and electronic equiment (WEEE). Directive 2002/96/EC.

Fleischmann, Moritz (2001): Reverse Logistics Network Structures and Design.

Forrester, Jay Wright (op. 1961): Industrial dynamics. Cambridge, MA, New York: M.I.T. Press; Wiley.

Gassmann, Oliver; Csik, Michaela; Frankenberger, Karolin (2013): Geschäftsmodelle entwickeln. 55 innovative Konzepte mit dem St. Galler Business Model Navigator. München: Hanser.

Gobbi, Chiara (2008): The reverse supply chain: configuration, integration and profitability. Considerations derived from a qualitative case study investigation. [1. oplag]. Kgs. Lyngby: Department of Management Engineering, Technical University of Denmark.

Gupta, Surendra M. (2012): Reverse Supply Chains. Issues and analysis, checked on 10/15/2014.

Jacobson, S. H.; Yucesan, E. (2002): Common issues in discrete optimization and discrete-event simulation. In *IEEE Trans. Automat. Contr.* 47 (2), pp. 341–345. DOI: 10.1109/9.983377.

Komoto, Hitoshi; Masui, Keijiro; Tomiyama, Tetsuo (2013): Quantitative scenario-based simulation of global business models for manufacturers. In *CIRP Annals - Manufacturing Technology* 62 (1), pp. 163–166. DOI: 10.1016/j.cirp.2013.03.088.

Law, Jonathan (2009): A Dictionary of Business and Management: Oxford University Press.

Lehr, Christian B.; Thun, Jörn-Henrik; Milling, Peter M. (2013): From waste to value – a system dynamics model for strategic decision-making in closed-loop supply chains. In *International Journal of Production Research* 51 (13), pp. 4105–4116. DOI: 10.1080/00207543.2013.774488.

Mansvelt, J. (2011): Green Consumerism: An A-to-Z Guide: SAGE Publications. Available online at https://books.google.de/books?id=gUy0dhwdCPMC.

Murayama; Hatakenaka; Oba: Simulation-based evaluation of forward and reverse supply chain. In : 2003. 3rd International Symposium on Environmentally Conscious Design and Inverse Manufacturing - EcoDesign'03. Tokyo, Japan, pp. 521–526.

Novoszel, Thomas (2012): Gestaltung einer integrativen Reverse Supply Chain. 1. Aufl. Aachen: Apprimus-Verlag (Edition Wissenschaft Apprimus, 113).

Osterwalder, Alexander; Pigneur, Yves (2011): Business Model Generation. Ein Handbuch für Visionäre, Spielverämderer und Herausforderer. Frankfurt: Campus Verlag.

Östlin, Johan; Sundin, Erik; Björkman, Mats (2008): Importance of closed-loop supply chain relationships for product remanufacturing. In *International Journal of Production Economics* 115 (2), pp. 336–348. DOI: 10.1016/j.ijpe.2008.02.020.

Raychaudhuri, Samik: Introduction to Monte Carlo simulation. In : 2008 Winter Simulation Conference (WSC). Miami, FL, USA, pp. 91–100.

Saunders, Mark; Lewis, Philip; Thornhill, Adrian (2012): Research methods for business students. 6. ed. Harlow: Financial Times Prentice Hall.

Schmitt, Amanda J.; Singh, Mahender: Quantifying supply chain disruption risk using Monte Carlo and discrete-event simulation. In : 2009 Winter Simulation Conference - (WSC 2009). Austin, TX, USA, pp. 1237–1248.

Seco, Alexandra; Vieira, Carlos (2014): A Multi-agent Supply Chain Simulation Analysis through a Statistical Mixed Model. In *Procedia Technology* 16, pp. 163–171. DOI: 10.1016/j.protcy.2014.10.079.

Sichman, Jaime S.; Conte, Rosaria; Gilbert, G. Nigel (1998): Multi-agent systems and agent-based simulation. First International Workshop, MABS '98, Paris, France, July 1998 : proceedings. Berlin, New York: Springer (Lecture notes in computer science Lecture notes in artificial intelligence, 1534).

Song, Danxia; Huang, Weilai; Xu, Yang: Performance evaluation of professional service supply chain based upon DEA & AHP models. In : 2008 IEEE International Conference on Service Operations and Logistics, and Informatics (SOLI). Beijing, pp. 2210–2215.

Tao, Xiaoyan: Performance Evaluation of Supply Chain Based on Fuzzy Matter-Element Theory. In : 2009 International Conference on Information Management, Innovation Management and Industrial Engineering. Xian, China, pp. 549–552.

The European Parliament and Council (9/26/2006): DIRECTIVE 2006/66/EC on batteries and accumulators and waste batteries and accumulators, DIRECTIVE 2006/66/EC. In : http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2006:266:0001:0014:en:PDF.

Thierry, Martijn; Salomon, Mar; van Nunen, Jo; van Wassenhove, Luk N.: Strategic Issues in Product Recovery Management. In *California Management Review* 1995 / 37.

Umeda, Shigeki (2013): Simulation Analysis of Supply Chain Systems with Reverse Logistics.

Ventana Systems Inc.: Vensim Software. Available online at http://vensim.com/vensim-software/, checked on 2/19/2015.

Vlachos, Dimitrios; Georgiadis, Patroklos; Iakovou, Eleftherios (2007): A system dynamics model for dynamic capacity planning of remanufacturing in closed-loop supply chains. In *Computers & Operations Research* 34 (2), pp. 367–394. DOI: 10.1016/j.cor.2005.03.005.

Wirtz, Bernd W. (2013): Business Model Management. Design, Instrumente, Erfolgsfaktoren von Geschäftsmodellen. 3., aktuelle u. überarb. Aufl. Wiesbaden: Springer Gabler.

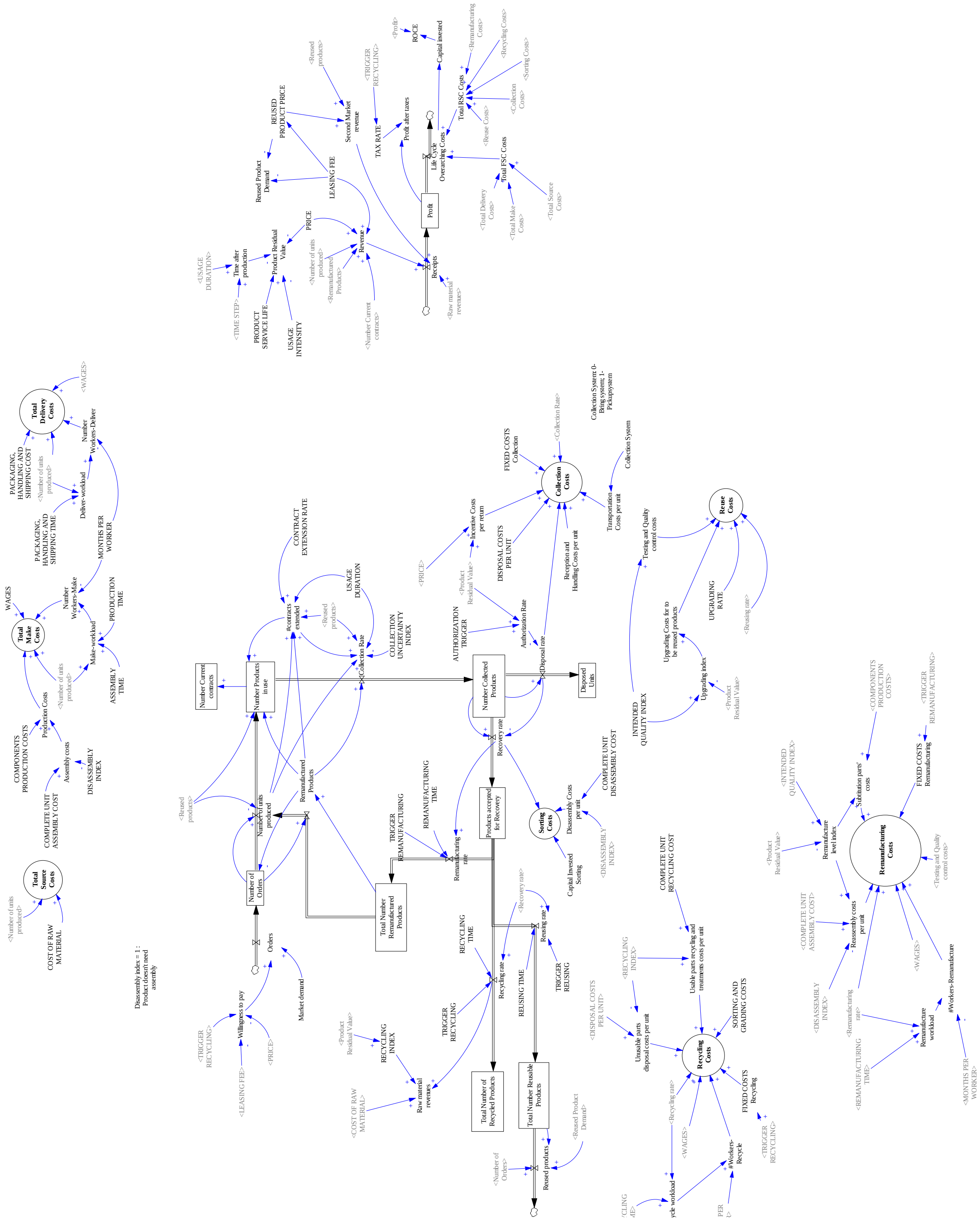
Zimmermann, Lisa (2013): Erfolgsfaktoren der Geschäftsmodelle junger Unternehmen. Stuttgart: Kohlhammer (Mittelstand und Mittelstandsforschung).

Zott, Christoph; Amit, Raphael; Massa, Lorenzo: The Business Model. Theoretical roots, recent developments and future research. IESE Business School.

Annexes

Annex A: SCOR model adaptation's process structure (according to (Novoszel 2012))

Annex B: Complete VENSIM evaluation model



Annex C: Model constants and variables

Assembly costs= -COMPLETE UNIT ASSEMBLY COST*DISASSEMBLY INDEX+COMPLETE UNIT ASSEMBLY COST

Units: €/WIDGET

ASSEMBLY TIME= 0.0007

Units: Month

Authorization Rate=AUTHORIZATION TRIGGER*Product Residual Value

Units: Dmnl

AUTHORIZATION TRIGGER=1

Units: Dmnl [0,1,0.1]

Capital invested=Life Cycle Overarching Costs

Units: €

Capital Invested Sorting=10000+2000*PULSE TRAIN(12, 1, 12, 120)

Units: €

Collection Costs = Collection Rate*(Transportation Costs per unit+Reception and Handling Costs per unit*Incentive Costs per return)+(Disposal rate*DISPOSAL COSTS PER UNIT)^0.6+FIXED COSTS Collection

Units: €/Month

Collection Rate=DELAY FIXED(MAX((Number of units produced+Number contracts extended+Remanufactured Products+Reused products)*(1-COLLECTION UNCERTAINTY INDEX),0), USAGE DURATION ,0)

Units: WIDGET/Month

Collection System= 0

Units: Dmnl

COLLECTION UNCERTAINTY INDEX= 0.05

Units: Dmnl [0,1,0.1]

COMPLETE UNIT ASSEMBLY COST= 10

Units: €/WIDGET

COMPLETE UNIT DISASSEMBLY COST=3

Units: €/WIDGET

COMPLETE UNIT RECYCLING COST=2

Units: €/WIDGET

COMPONENTS PRODUCTION COSTS=45

Units: €/WIDGET

CONTRACT EXTENSION RATE=0

Units: Dmnl [0,1,0.1]

COST OF RAW MATERIAL=40

Units: €/WIDGET

Deliver-workload=("PACKAGING, HANDLING AND SHIPPING TIME")*Number of units produced

Units: Month

Disassembly Costs per unit=COMPLETE UNIT DISASSEMBLY COST*(1-DISASSEMBLY INDEX)

Units: €/WIDGET

DISASSEMBLY INDEX=0.7

Units: Dmnl

DISPOSAL COSTS PER UNIT=5

Units: €/WIDGET

Disposal rate=INTEGER(Number Collected Products*(1-Authorization Rate))

Units: WIDGET/Month

Disposed Units= INTEG (Disposal rate, 0)

Units: WIDGET

FINAL TIME = 180

Units: Month

The final time for the simulation.

FIXED COSTS Collection=(PULSE (0,1)*10000+2000*PULSE TRAIN(12, 1, 12, 120)+50)

Units: €

FIXED COSTS Recycling=If then else(TRIGGER RECYLING=1,(PULSE(0,1)*10000+6000*PULSE TRAIN(12,1,12,120)),0)

Units: €

FIXED COSTS Remanufacturing=If then else(TRIGGER REMANUFACTURING=1,(PULSE(0,1)*20000+5000*PULSE TRAIN (12,1,12,120)),0)

Units: €

Incentive Costs per return=0.02*PRICE*0+Product Residual Value*0.05*PRICE

Units: €/Month

INITIAL TIME = 0

Units: Month

The initial time for the simulation.

INTENDED QUALITY INDEX=0.8

Units: Dmnl

LEASING FEE=0

Units: €/WIDGET/Month

Life Cycle Overarching Costs=Total FSC Costs+Total RSC Costs

Units: €/Month

Make-workload=(PRODUCTION TIME+ASSEMBLY TIME)*Number of units produced

Units: Month

Market demand=INTEGER(RANDOM UNIFORM(200,700,1))

Units: WIDGET/Month

MONTHS PER WORKER=20*8/(24*30)

Units: Month

Number Collected Products= INTEG (Collection Rate-Disposal rate-Recovery rate,0)

Units: WIDGET

Number contracts extended=DELAY FIXED(MAX(0,CONTRACT EXTENSION RATE*(Number of units produced+Remanufactured Products

+Reused products)), USAGE DURATION, 0)

Units: WIDGET/Month

Number Current contracts=Number Products in use

Units: WIDGET

Number of Orders= INTEG ((Orders-Number of units produced-Remanufactured Products),
0)

Units: WIDGET/Month

Number of units produced=MAX(Number of Orders-(Reused products+Remanufactured Products),0)

Units: WIDGET/Month

Number Products in use= INTEG(INTEGER(Number of units produced+Remanufactured Products+Reused products+Number contracts extended-Collection Rate),0)

Units: WIDGET

Number Workers-Deliver= INTEGER("Deliver-workload"/MONTHS PER WORKER)+1

Units: WIDGET

Number Workers-Make=INTEGER("Make-workload"/MONTHS PER WORKER)+1

Units: WIDGET

Number Workers-Recycle=INTEGER(Recycle workload/MONTHS PER WORKER)+1

Units: WIDGET

Number Workers-Remanufacture=INTEGER(Remanufacture workload/MONTHS PER WORKER)+1

Units: WIDGET

Orders=INTEGER(Market demand*Willingness to pay)

Units: WIDGET/Month

PACKAGING, HANDLING AND SHIPPING COST=10

Units: €/WIDGET

PACKAGING, HANDLING AND SHIPPING TIME=0.0002

Units: Month

PRICE=130

Units: €/WIDGET

Product Residual Value= If then else(Time after production>=PRODUCT SERVICE LIFE,0,(PRICE-(Time after production/PRODUCT SERVICE LIFE)*PRICE*

USAGE INTENSITY)/PRICE)

Units: Dmnl

PRODUCT SERVICE LIFE= 120

Units: Month [0,120,1]

Production Costs= Assembly costs+COMPONENTS PRODUCTION COSTS

Units: €/WIDGET

PRODUCTION TIME=0.0014

Units: Month

Production time per unit 1=0.01

Units: Month

Products accepted for Recovery= INTEG (Recovery rate-(Recycling rate+Remanufacturing rate+Reusing rate), 0)

Units: WIDGET

Profit= INTEG (Receipts-Life Cycle Overarching Costs,0)

Units: €

Profit after taxes=Profit*(1-TAX RATE)

Units: €

Raw material revenues=RECYCLING INDEX*(COST OF RAW MATERIAL)*Recycling rate

Units: €/Month

Reassembly costs per unit=Remanufacture level index*DISASSEMBLY INDEX*COMPLETE UNIT ASSEMBLY COST

Units: €/WIDGET

Receipts=Revenue+Raw material revenues+Second Market revenue

Units: €/Month

Reception and Handling Costs per unit= 5

Units: €/WIDGET

Recovery rate=INTEGER(MAX(Number Collected Products-Disposal rate,0))

Units: WIDGET/Month

Recycle workload=(RECYCLING TIME*Recycling rate)

Units: Month

Recycling Costs=(Unusable parts disposal costs per unit+SORTING AND GRADING COSTS+Usable parts recycling and treatments costs per unit)*Recycling rate+FIXED COSTS Recycling+WAGES*"Number Workers-Recycle"

Units: €/Month

RECYCLING INDEX=Product Residual Value

Units: Dmnl

Recycling rate=DELAY FIXED(TRIGGER RECYCLING*Recovery rate, RECYCLING TIME, 0)

Units: WIDGET/Month

RECYCLING TIME=0.005

Units: Month

Remanufacture level index=MAX(INTENDED QUALITY INDEX-Product Residual Value,0)

Units: Dmnl

Remanufacture workload= Remanufacturing rate*REMANUFACTURING TIME

Units: Month

Remanufactured Products=MIN(Number of Orders,Total Number Remanufactured Products)

Units: WIDGET/Month

Remanufacturing Costs=Remanufacturing rate*(Reassembly costs per unit+Subtitution parts' costs+ Testing and Quality control costs)+FIXED COSTS Remanufacturing+WAGES*Number Workers-Remanufacture

Units: €/Month

Remanufacturing rate=DELAY FIXED(Recovery rate*TRIGGER REMANUFACTURING, REMANUFACTURING TIME*Recovery rate, 0)

Units: WIDGET/Month

REMANUFACTURING TIME=0.0001

Units: Month

Reuse Costs=(Testing and Quality control costs+Upgrading Costs for to be reused products*UPGRADING RATE)*Reusing rate

Units: €/Month

Reused Product Demand= INTEGER(If then else(REUSED PRODUCT PRICE=0,exp(-(LEASING FEE)^2/(2*9^2))*RANDOM UNIFORM(500,700,1),RANDOM UNIFORM(500,700,1)*exp(-(REUSED PRODUCT PRICE-10)^2/(2*100^2))))

Units: Dmnl

REUSED PRODUCT PRICE=If then else(LEASING FEE=0,85,0)

Units: €/WIDGET

Reused products= MIN(MIN(Total Number Reusable Products,Reused Product Demand),Number of Orders)

Units: WIDGET/Month

Reusing rate=DELAY FIXED(TRIGGER REUSING*Recovery rate , REUSING TIME,0)

Units: WIDGET/Month

REUSING TIME= 0.0001

Units: Month

Revenue=If then else(LEASING FEE=0,(Number of units produced+ Remanufactured Products)*PRICE,LEASING FEE*Number Current contracts)

Units: €/Month

ROCE=Profit/Capital invested

Units: dmnl

SAVEPER = TIME STEP

Units: Month [0,?]

The frequency with which output is stored.

Second Market revenue=Reused products*(REUSED PRODUCT PRICE)

Units: €/Month

SORTING AND GRADING COSTS=2

Units: €/WIDGET

Sorting Costs=Disassembly Costs per unit*Recovery rate+Capital Invested Sorting

Units: €/Month

Subtitution parts' costs=COMPONENTS PRODUCTION COSTS*Remanufacture level index

Units: €/WIDGET

TAX RATE=(1-TRIGGER RECYCLING)*0.15

Units: Dmnl [0,1,0.5]

Testing and Quality control costs=2*exp(INTENDED QUALITY INDEX)

Units: €/WIDGET

Time after production= INTEG(TIME STEP-2*USAGE DURATION*PULSE TRAIN(2*USAGE DURATION, 0, 2*USAGE DURATION, 180),0)

Units: Month

TIME STEP = 1

Units: Month [0,?]

The time step for the simulation.

Total Delivery Costs=("PACKAGING, HANDLING AND SHIPPING COST"*Number of units produced)+WAGES*Number Workers-Deliver

Units: €/Month

Total FSC Costs=Total Delivery Costs+Total Make Costs+Total Source Costs

Units: €/Month

Total Make Costs= (Production Costs*Number of units produced)+WAGES*"Number Workers-Make"

Units: €/Month

Total Number of Recycled Products= INTEG(INTEGER(Recycling rate),0)

Units: WIDGET

Total Number Remanufactured Products= INTEG (INTEGER(Remanufacturing rate)-Remanufactured Products,0)

Units: WIDGET

Total Number Reusable Products= INTEG (INTEGER(Reusing rate-Reused products), 0)

Units: WIDGET

Total RSC Costs=(Collection Costs+Sorting Costs+Recycling Costs+Reuse Costs+Remanufacturing Costs)

Units: €/Month

Total Source Costs=(Number of units produced*COST OF RAW MATERIAL)

Units: €/Month

Transportation Costs per unit=If then else(Collection System=0,0,5)

Units: €/WIDGET

TRIGGER RECYCLING=0

Units: Dmnl [0,1,1]

TRIGGER REMANUFACTURING=0

Units: Dmnl [0,1,1]

TRIGGER REUSING=1

Units: Dmnl [0,1,1]

Unusable parts disposal costs per unit=DISPOSAL COSTS PER UNIT*(1-RECYCLING INDEX)

Units: €/WIDGET

Upgrading Costs for to be reused products=10*Upgrading index^2

Units: €/WIDGET

Upgrading index=If then else(Product Residual Value>INTENDED QUALITY INDEX,0,INTENDED QUALITY INDEX-Product Residual Value)

Units: Dmnl

UPGRADING RATE=0.2

Units: Dmnl

Usable parts recycling and treatments costs per unit= COMPLETE UNIT RECYCLING COST*RECYCLING INDEX

Units: €/WIDGET

USAGE DURATION=12

Units: Month

USAGE INTENSITY=0.2

Units: Dmnl [0,1,0.1]

WAGES=8.5*8*20

Units: €/(WIDGET*Month)

Willingness to pay= If then else (LEASING FEE = 0, If then else(TRIGGER RECYCLING=1,exp(-(PRICE-10)^2/(2*140^2)),exp(-(PRICE-10)^2/(2*130^2))),If then else(TRIGGER RECYCLING =1,exp(-(LEASING FEE)^2/(2*10^2)),exp(-(LEASING FEE)^2/(2*8^2))))

Units: Dmnl